LANCHAD

REMOTE SENSING OF THE N'DJAMENA AREA AND THE LOGONE-CHARI CONFLUENT

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16. Abstract

The article discusses the Republic of Chad's experimental beginnings of a program of Earth resources inventory utilizing remote sensing from satellites. The program contemplates utilization of data from LANDSAT 1 and 2, NOAA, METEOSAT and SPOT. Work is continuing through a collective group including the planning and development authority of Chad, the University of Chad, the O.R.S.T.O.M. and the University of Paris.

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Diachronic and Multispectral Cartography at 1/50,000 and 1/100,000

Claude Bardinet*, Jean-Marie Monget**

FOREWORD

For an understanding of the Earth and for an inventory of its resources, remote sensing from satellites offers a new means, the possibilities of which one is only beginning to perceive, and which supplement rather than substitute for the previous modes of inventory. Satellites are furnishing, in increasing torrents without cease, data on the totality of our planet. For the Republic of Chad, LANDSAT 1, LANDSAT 2, the NOAA series, METEOSAT, and doubtless soon SPOT, have furnished, are furnishing, and will furnish a mass of multispectral data-thermographics, the exploitation of which has today widely begun — at least under the heading experimental; but the time is near in which such exploitation will comprise a necessary foundation for all undertakings for economic development and management of the area. /2***

The LANDSAT data in particular appear well suited to the geographic study of the Republic of Chad because they allow the establishment of cartography at the 1/50,000 scale more detailed than that which has been available until now. Their spatial resolution also

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***Numbers in the margin indicate pagination in the original foreign text.

permits a good recognition of the regional boundaries which delineate homogeneous characteristics over fairly large surface areas. Finally, by their rapid time sequence, they permit a grasp of the variations in the vegetative cover and of the water areas.

In addition to these general advantages, remote sensing offers another — that of the rapidity of data acquisition. To this must be added that of the processing and distribution of the results, because states prefer the preparation of true living atlases, continuously updated, basic to the undertaking of economic development, rather than an historic atlas based on conditions already past in which a retrospective understanding is much less useful.

This section presents the first results of the LANCHAD remote sensing program. One will see that this new tool for geographic research bases its interpretations on a necessary association of the knowledge of the terrain and the processing of the data by computer.

Fernand Verger
Professor, École Normale Supérieure

INTRODUCTION

The LANCHAD Atlas is a part of the regional atlas of Chad, the work on which began in 1977 at the request of the Ministry for Economics, Planning, and Transportation of Chad made to the Fund for Aid and Cooperation. /3

These regional atlases have been conceived principally to be a collective work by the following entities: Planning and Development Authority of Chad, the University of Chad, O.R.S.T.O.M., and the University of Paris I.

The scientific committee for this atlas was set up by Jean Cabot, Professor at the University of Paris VIII, Daniel Noin, Professor at the University of Paris I, and Gilles Sautter, Professor at the University of Paris I.

The section "Atlas LANCHAD" has been directed by Fernand Verger, Professor at the Montrouge Teachers College. The present publication LANCHAD has been carried out by Jean-Marie Monget, Director of the Center for Remote Sensing and Analysis of the Natural Environment at the National College of Mines in Paris and by Claude Bardinet, Instructor at the Laboratory for Cartography at the University of Chad. On September 30, 1977, the team which had collaborated on the LANCHAD project also included Michel Albuisson and Michel Poisson of the Center for Remote Sensing and Analysis of the Natural Environment.

The automated cartography was done at C.I.R.C.E. of C.N.R.S. in collaboration with Gerard Joly.

Anne Le Fur (University of Paris I - E.S.C.G.) put together the dummy press layouts for the press at C.E.R.C.G. of C.N.R.S.

The financing of this first phase of LANCHAD was provided by the F.A.C. within the framework of an interuniversity accord between the University of Chad and the University of Paris I.

The methodology used is that perfected in the framework of the Fralit team (RCP 353 of the C.N.R.S.) by the C.T.A.M.N. The thematic cartography of the regions is here derived by a numerical treatment of the multispectral data obtained using satellite remote sensing. The relationships existing between the nature of the objects on the ground and their multispectral signature permit a computer-assisted exploration and cartography of the regions. In the spectral regime of the LANDSAT satellite (visible and near infrared) the dominant problems are linked to chlorophyll, to water and to the nature of the soil, while for the NOAA satellites (thermal IR), the phenomena observed are more physical: geology, geomorphology, climatology.

CHAPTER 1 - HISTORY OF THE LANCHAD ATLAS

The LANCHAD atlas project was carried out within the framework /4
of the interuniversity accord associating the University of Chad and the University of Paris I in the development of, teaching of, and research in geographical cartography.

Geographical cartography being, in this choice, principally considered to allow the creation of maps useful for the management of the area, the thought has led to a regional type of atlas which has been lacking for the planner in our times. The coincidence of this objective of university research and of the request expressed by the Chad planners who wanted to quickly arrange a cartographic inventory of Chad in the human, economic, and physical regimes, led to the organization of a symposium* at N'Djamena on the subject of "Regional Atlases of Chad and Regionalization of the Plan". Of the different subjects covered in the course of this symposium, we will here recall the one entitled: "The LANCHAD Project: Remote Sensing and Cartography of Chad".

The term LANCHAD, being indeed the contraction of "LANDSAT Imagery of Chad" for "Land Use in Chad", is the term chosen to emphasize that one intends to use the LANDSAT recordings for practical studies on the management of Chad territory.

The first work in actual application of remote sensing techniques to the imagery of Chad was introduced in September 1976, after a one-year study period in the course of which different studies on the handling of the imagery were successively considered

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*This symposium was convened at the University of Chad on January 14-15, 1977, consisting of the geographers from the University of Paris, J. Cabot, D. Noin, B. Rouleau, and G. Sautter, the university staffs, planners of Chad and of researchers; the work will be published by the University of Paris I. C. Bardinet read the paper "Project LANCHAD: Dichronic Analysis of the LANDSAT Remote Sensing Imagery of Chad in the N'Djamena Zone at 1/50,000 and 1/200,000.

by C. Bardinet, in taking account of the experience acquired at the School of Advanced Applied Studies and the School of Advanced Studies in Social Science, and by the teams brought together, one around F. Verger (Fralit) and the other around J.-P. Gilg and G. Sautter.

It is finally the methodology of the numerical processing program for tapes developed in the framework of the Fralit effort* which was employed to create the maps presented in this first LANCHAD publication. The work method is called that of spectral association /5
and taxonomical association after analysis. J.-M. Monget led the unmonitored analysis, and C. Bardinet — the monitored. The FRACAM** system used was developed at the C.T.A.M.N. of the National College of Mines in Paris.

The test zone presented in these first sections is that of N'Djamena (formerly Fort Lamy), capital of Chad, at the regional scales of 1/50,000, 1/100,000, 1/200,000 and 1/500,000.

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* The Fralit Team - "Remote Sensing of the Oceanic Littoral of France". Collection de l'Ecole Normale Superieure de Jeunes Filles, No. 11, 1977, 310 pp.

** J.-M. Monget - Automated Classification of Multispectral Data Using Harmonic Analysis. The CLAMS System. Bulletin of the French Society of Photogrammetry, 1967 - 62, pp. 15-23.

CHAPTER 2 - THE GEOGRAPHICAL SETTING

The N'Djamena zone (12°6 north and 15° east for the center of the cluster) experiences a climate of the Sahel type with two seasons — a wet season from June to September and a dry season from October to May. Rain measurements are on the order to 600 mm per year with strong variations during the years (602.8 mm in 1972, 314.7 mm in 1973, and 990.1 mm in 1959, according to Tobias ORSTOM, 1976). /6

The atmospheric humidity varies from 80% in August to 21% in March. Northeast winds predominate. The mean annual temperature is 28°, with a minimum of 14° in January and a maximum of 41° in April (27-year averages established by ORSTOM). Diurnal variations are important in all seasons, and can reach 20° in January and 8° in August. The annual evaporative transpiration was estimated by Tobias (1976) at 1900 mm.

2.1. The soils

A study of the soils (Pias and Barberry, ORSTOM, 1964) is possible from the 1/200,000 map.

2.1.1. The right bank of the Chari-N'Djarema zone

One observes the following dominances:

Halomorphic alkaline soils of generally temporary hydromorphy:

- cultivated soils in topographical depressions, related to argilaceous materials (black tropical argile);
- soils of clay and pseudo-clay in patches and concretions, related to recent sand-silt and clay-silt alluviations (lateral ridging of the wadis and the drainages).

2.1.2. <u>The left bank of the Chari and the Logone-Chari confluence</u>

One observes the following dominances:

- cultivated soils in topographical depressions, soils of clay related to argilaceous material, here and there in chalky nodules;
- hydromorphic mineral soils generally of semi-permanent hydromorphy:

  - clay and pseudo-clay soils in patches and concretions, related to recent sand-silt and clay-silt alluviations (depressions and terracing of the Chari and the Logone), generally of semipermanent hydromorphology;
  - hydromorphy general, or of temporary depth, clay and pseudo-clay in patches and concretions, related to recent sand-silt or clay-silt, lateral ridging in wadis and drainage;

- complex hydromorphic-deposition (interfluvial) soils with alternate: /7

  - raw hydromorphic soils of sand or sandy argiles;
  - soils of argilaceous material here and there in chalky nodules.

<u>One observes a very great heterogeneity of materials at the outcroppings</u>.

The floodable areas are either of the recent argilaceous lacustrian series or of the recent sandy series of fluvial origin. The features above the water are either rims of the bank or of water courses or the contours of the old sandy series. The pumping of underground water slightly entrains the presence of salts.

2.1.3. <u>The meanders in the Chari and the Logone in the N'Djamena zone</u>

They are characterized by:

- the recent sandy series of features of quartzite sand,
- argilaceous stratification
- the old argilaceous-sandy series of chalky nodules (banks of the Chari),
- the older alluvial series with current fine textured silt, silt-clays, and clay-silts (ridging of the banks of the rivers and tributaries, terraces and principal layers).

The nature of the material on the surface determines in large part the level of reflectance recorded using remote sensing. Tobias (1976) determines in this zone four principle types of soils, either:

- <u>hydromorphic soils</u> on the rims of the bank, silty, of an excess of water (useable reserve drained off dry in 24 days), fine textured, compact, slight permeability;
- <u>ferruginous tropical soils</u> of deep sandy material, fine textured, sandy on the surface, argilaceous at depth, compact and not much permeability (useable water reserve drains very dry in 4 days);
- <u>cultivated soils</u> "Berbere (sorghum) and "Karal", clay content elevated at the surface, heavy soils, fine constituents, argilaceous minerals swelling with the formation of mud when water soaked and cracking with dessication in the dry state, slight permeability (useable reserve of water drains off dry in 10 days);
- halomorphic soils or nagas, horizon sandy on the surface, of variable thickness, impermeable at the argilaceous level, retention of water slight (reserve of useable water drains off in 5 days in dry season).

2.2. The vegetation

In this zone, Pias (1968) observes six type of vegetation.

2.2.1. Sandy wooded savanna (north of N'Djamena), partially on the rims of old or current watercourses and partially hydromorphic raw alkaline soils, dominated by Acacia senegalensis, Balanites aegyptiaca, Acacia seyal, second growth of Hyphaena thebaica.

2.2.2. Vegetation on bottomlands and on nagas soils

The nagas soils are often dispersed and surrounded by flooded lowlands. The lowlands are wooded as a function of soil texture. The vegetation is composed of:

- small islands of dense vegetation, tall trees, Zizyphus mauretania, Acacia seyal, Anogeissus leiocarpus and gramineous carpets of tall beard grass;
- open savanna on black tropical argile, Acacia seyal, and tall beard grass;
- Acacia seyal and Acacia scorpioides on the ponds marking out the nagas soils.

2.2.3. The undergrowth

Borassus aethiopum, Ficus, Faidherbia labida, Balanites aegyptiaca, Calotropis procera, on light textured soils where the water table is near the surface.

2.2.4. The marshy plain and the flood plains of the Logone

This type includes the flooded areas of the rivers during the rainy season, the interior basins, the edges of the wadis, the permanent marshes. Here flooding is variable from August to December. The vegetation includes:

- in general, a gramineous carpet of beard grasses on hydromorphic argilaceous soils;
- in the low lying areas forming puddles in the dry season, a carpet of Nymphea lotus;
- on the edge of the flood plains or on knolls 5 - 6 meters above the water, Fisuc, Borassus aethiopum, Faidherbia albida, Hyphaene thebaica, Tamarindus indica, Kigelia africana...

2.2.5. <u>The forest arcade, densely wooded savanna</u> /9

This is localized on the rim of the Chari and in part on that of the Logone. The alluvial soils of recent origin, with an acid pH, of argilaceous silt texture support:

- large trees, all types of acadia, Mitragyna Africana, Hyph Hyphaene Thebaica, Ficus Divers, Zizyphus Jujuba;
- thickets of shrubs and thorns, Zizyphus Mauretania, acacia, Combretum ...
- in the low lying areas a pure population of Acacia seyal (including in the courses of the argilaceous wadis), along the banks, spiny bushes, mimosa asperata...

2.2.6. <u>The open savanna of black tropical argile</u>

This is a savanna of little or of limited flooding. One finds Acacia Seyal and Mitragyna Africana.

2.3. <u>Cultivation</u>

In the period of observation, at the beginning of the dry season from October to February, there is principally seen:

- cultivation of the sorghum called "berbere" in the low lands;
- truck farming of the more recent alluvial series of fine silty loam with a little mica content (Tobias), principally on the rims of the river banks and on the terraces in proportion to the water table.

CHAPTER 3. THE INFORMATION METHODS EMPLOYED

They comprise three information system of different characteristics, each belonging to a particular administrative entity, namely: /10

- the Information Processing and Industrial Statistical Service (STISI) of the Ministry of Industry, Commerce, and Handicrafts (MICA) equipped with a CII-IRIS 80 digital processing system;
- the National College of Mines of Paris (ENSMP) equipped with an HP-2100 system;
- the Interregional Center for Computers (CIRCE) of the National Center for Scientific Research, equipped with an IBM 370-175 digital processing system.

Each of these information systems was used in a particular mode to support the programs developed either by CTAMN or by the Laboratory for Geography of the ENSJF (F. Verger).

3.1. The CII-IRIS 80 system of STISI

The Computer Center of STISI is equipped with a CII-IRIS 80 biprocessor with a one-million 32-bit word memory functioning with a variety of peripherals, such as bulk storage disks (200 million 8-bit bytes) and 9-track, 1600 BPI tape decks.

The ENSMP is connected to this computer by virtue of the participation of its parent ministry (MICA) which lacks information systems. Thus, the CTAMN has the possibility of using this system in one of its two modes: operation by block share or by time sharing.

For the remote block sharing, the ENSMP at Sophia Antipolis is equipped with a larger terminal SEMS-MITRA (Figure 3-A) connected to the STISI computing center at Voluceau by a line of 9600 baud capacity. The large terminal is composed of the following elements:

- a SEMS-MITRA minicomputer 15 with a memory of 16K 16-bit words;
- a card readout;
- a printer;
- a command console.

This mode of operation is used by the DUERB, LICLA, AND DUCLA programs developed at CTAMN:

- the DUERB program transfers the data received from the EROS DATA CENTER on magnetic tape to bulk storage disk, thereby permitting a subsequent use of the data in time sharing.
- The LICLA program creates a printed version (listing) of the classification results using a variable key. /12
- The DUCLA program enables a transfer of the classification results to magnetic tape thus permitting them to be used on the IBM-370 system at CIRCE.

For shared time operation, the CTAMN at Sophia Antipolis is equipped with a small TEKTRONIX terminal (Figure 3-A) connected to the computing center of STISI at Voluceau by a line of 200 bauds capacity. This small terminal is composed of the following elements:

- a TEKTRONIX 4006 display console,
- a hard-copy system on TEKTRONIX thermosensitive paper.

This mode of interactive operation is used by the FRACAM system of classification developed at the CTAMN. We will review in more detail (in Chapter 5) the different programs which comprise this system. They simply specify that the classification records are able to be produced at a scale that varies continuously from 1/25,000 to 1/1,000,000.

3.2. The HP-2100 system at CTAMN

For their own needs, the Center for Remote Sensing and Analysis of the Natural Environment (CTAMN) is equipped with an autonomous

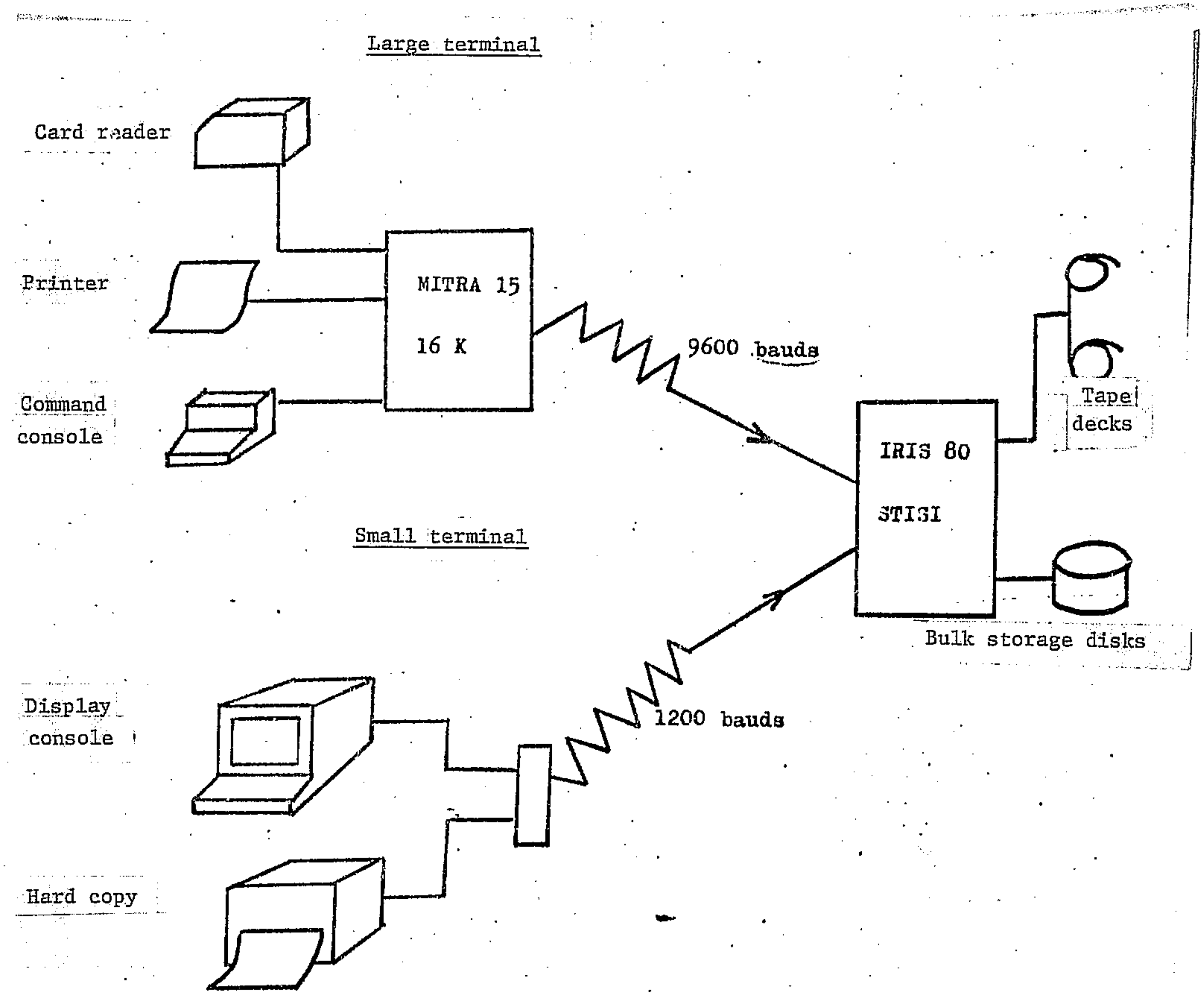


Figure 3-A. The two modes of operation of the IRIS 80 computer at STISI

processing system constructed around the Hewlett-Packard 2100 minicomputer (Plate A). It comprises the following elements:

- a minicomputer HP-2100 with a 16K 16-bit word memory;
- two storage disks, each of 10 M 8-bit byte capacity;
- a tape deck of 9 tracks-800 BPI;
- a TEKTRONIX 4013 display console;
- a VERSATEC 1200A printer-plotter.

This processing system is used by the DUPSTR and VISTR programs developed at CTAMN.

- The DUPSTR program permits the transfer to disk storage of the data received from the EROS DATA CENTER on magnetic tape, this choice perhaps associated with the spectral criteria utilizing one of the channels (MSS 7 for example).

- The VISTR program creates a printout of selected data in the form of a black and white document of ten gray scale levels using the VERSATEC printer-plotter. These printouts can be created at different scales, respectively: 1/1,000,000, 1/500,000, 1/400,000, 1/300,000/ 1/200,000, and 1/100,000. The base used is either white paper or transparent tracing paper.

This method of cartography has been used within the framework of the LANCHAD project to print out the data from the LANDSAT and NOAA 5 satellites. /14

3.3. The IBM 370 system at CIRCE

The CIRCE Computer Center is equipped with an IBM 370-175 system of great capacity, functioning with the classical peripherals (9T-1600 BPI tapes and disks), as well as special peripherals among which is an incremental plotter of the BENSON type.

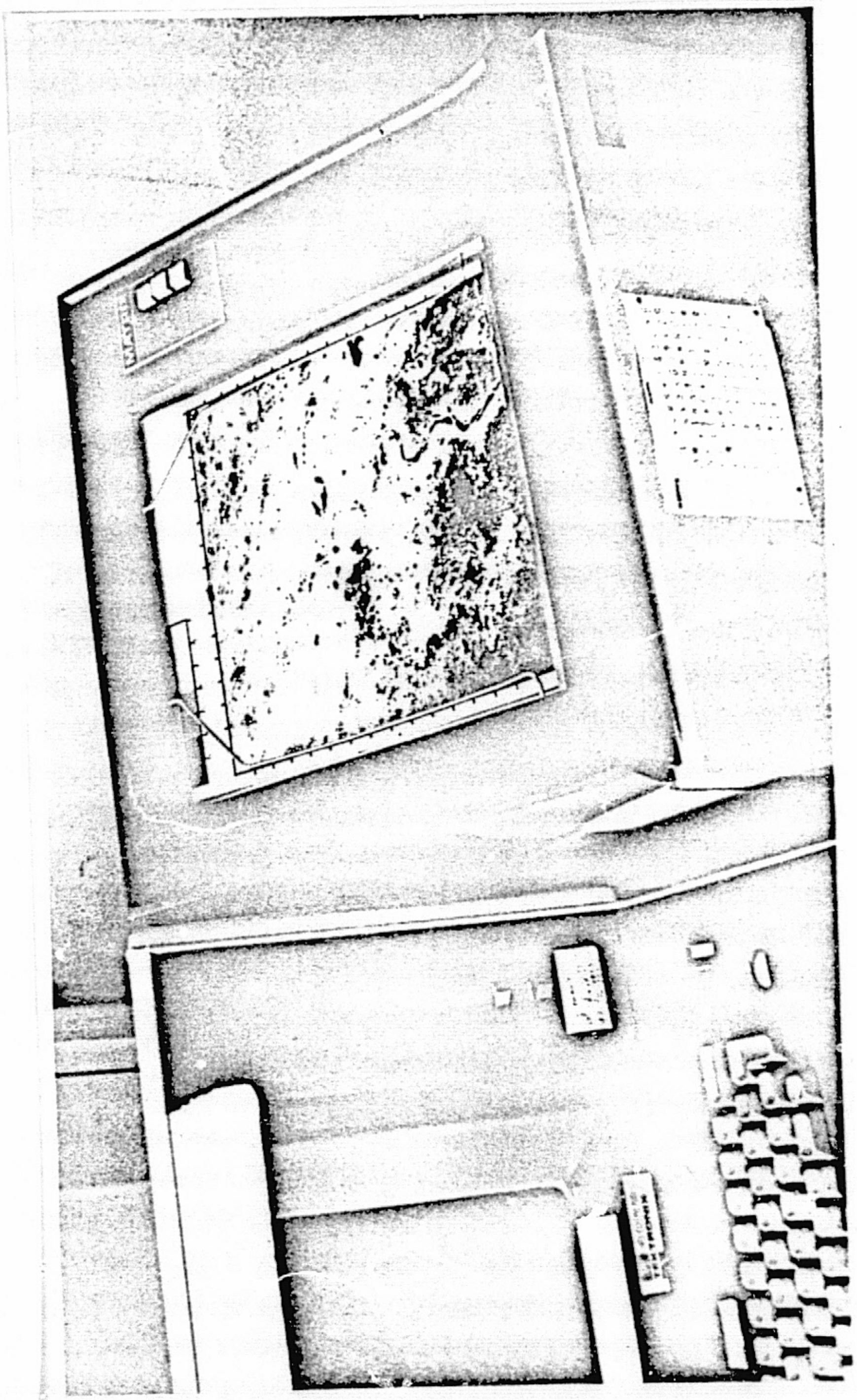
System of remote sensing data processing using a minicomputer (processing center of the CTAMN, College of Mines)

Plate A. Different elements of the automated processing system used for the LANCHAD project

(Plate continued on following page)

This apparatus permits the creation of color maps from the classification output using the FRACARTO cartographic system developed in the Laboratory for Geography of the ENSJF.

These maps can be generated at all scales running from 1/1,000,000 to 1/50,000, either directly as polychrome maps on opaque paper, or as a series of prints corresponding to each color of the printed map, each of such prints being plotted in black ink on transparent paper of the first quality (mylar).



Interactive console associated with a printed map plot

Plate A. (continued)

3.4. An example of processing (FOR 3)

In order to familiarize the reader with the times of operation pertaining to remote sensing data processing, we present an example of this in the case of data processing for the N'Djamena area on January 12, 1973 (FOR 3).

3.4.1. Utilization of the CII-IRIS 80 system

- selection of a test zone in the neighborhood of 40,000 pixels: 1 minute of computer time;
- classification of test zone data: 40 minutes of computer time for a real time of about 6 hours of display console in the time sharing mode;
- choice of a printout legend: 2 minutes of computer time;
- transfer of the classification data to magnetic tape for use in the CIRCE plotter: 2 minutes of computer time.

3.4.2. Use of the HP-2100 system

- choice of the stipulated area of about 900,000 pixels: 20 minutes of computer time;
- cartography at a 1/100,000 scale on the printer-plotter: 75 minutes of use time.

3.4.3. Use of the IBM-370 system /15

- generation of information on the sequence of plots using the classification output from the test zone: 1 minute of computer time;
- plotting of a polychrome map at a 1/50,000 scale: 20 minutes of use time.

CHAPTER 4 - LANDSAT AND NOAA DATA ON CHAD

4.1. LANDSAT 1 Data on Chad /16

The N'Djamena area, capital of Chad, having been reserved as the test zone, the data used are those of the following three frames:

- E 1101 08515, November 1, 1972,
- E 1173 08513, January 12, 1973,
- E 1209 08521, February 17, 1973.

These three frames have been selected in the series of those recorded by NASA like that appearing in the cumulative list issued by the EROS DATA CENTER (Figure 4.A).

The choice of the dates booked was motivated by the idea of comparing the landscape observed between the end of the rainy season (November, 1972), the end of the cool period (January, 1973), and the dry and hot mid-period (February, 1973). Between these three dates, the evolution of the countryside is in effect strongly marked by the disappearance of the wet areas, the very great lowering of the ponds and puddles, the drying-up of the vegetation and the lowering of the river waters.

The N'Djamena zone (12°10 north, 15°00 east) is situated in the upper quarter of the two strips 3 and 4 of the frame.

4.1.1. The photometric parameters

4.1.1.1. Image E 1101 08515, November 1, 1972

- Geographical coordinates of the center: 11°28 N, 14°35 E.
- Geographical coordinates of the nadir point: 11°24 N, 14°39 E.

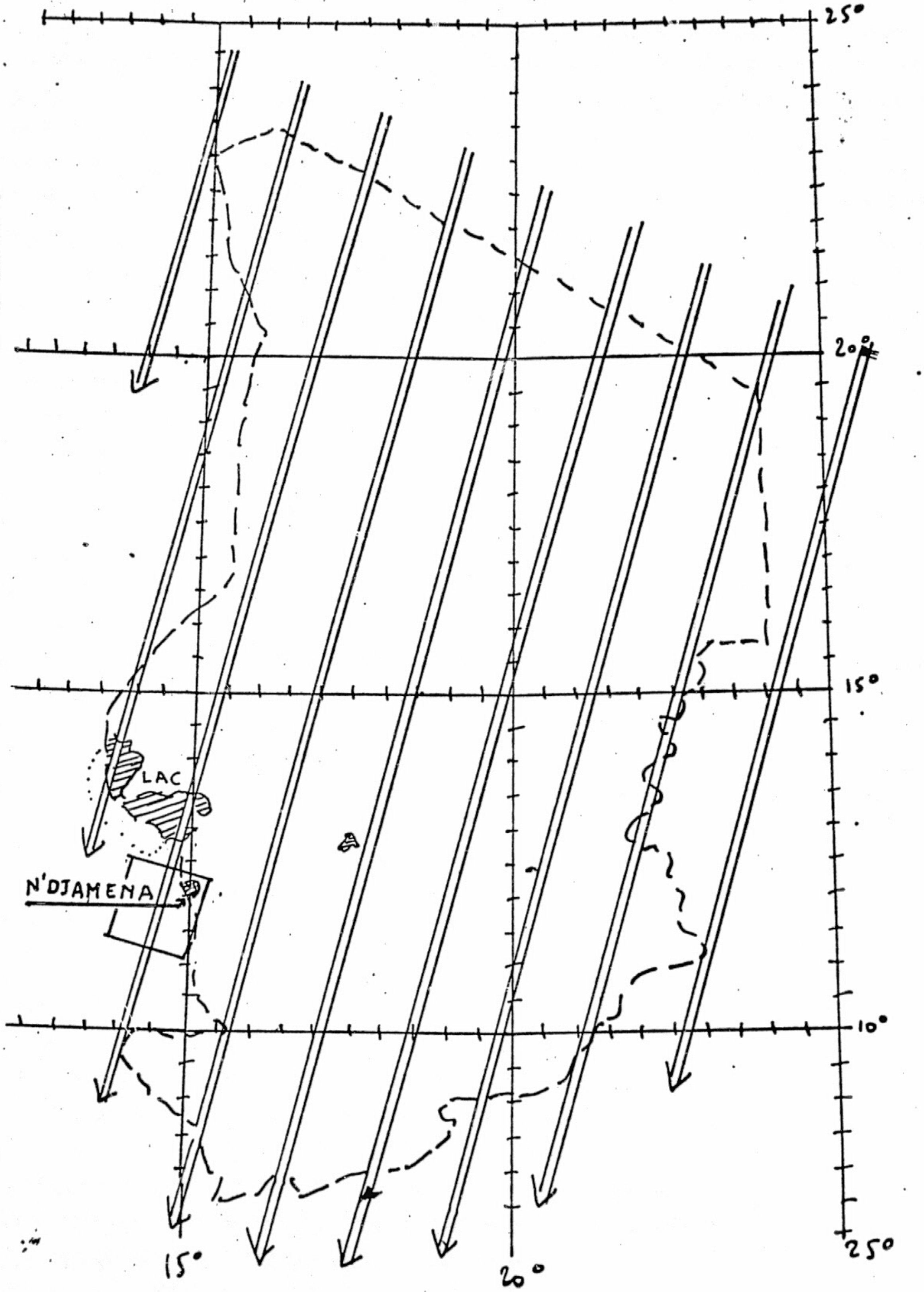


Figure 4.A. LANDSAT orbital traces of Chad

- Solar elevation: 51°.
- Solar azimuth of the radiometer: 132°.

4.1.1.2. Image E 1173 08513, January 12, 1973

- Geographical coordinates of the center: 11°30 N, 14°40 E.
- Geographical coordinates of the nadir point: 11°26 N, 14° 46 E;
- Solar elevation: 42°.
- Solar azimuth of the radiometer: 134°.

4.1.1.3. Image E 1209 08521, February 17, 1973

- Geographical coordinates of the center: 11°39 N, 14°33 E.
- Geographical coordinates of the nadir point: 11° 35 N, 14° 38 E.
- Solar elevation: 47°. /18
- Solar azimuth of the radiometer: 122°.

4.1.2. Processing code for the images

In the following text, each image will be designated by a code permitting the assembly of all the processing which pertains to it. The image E1101 of November 1, 1972 is called FOR 1; E 1209 of February 17, 1972 is FOR 2; E 1173 of January 12, 1973 is FOR 1.2, and the processing of dichronic images FOR 1 and FOR 2.

4.2. The LANDSAT 2 data on Chad

The data used are those in the following three frames:

- E 2259 08384, October 8, 1975;
- E 2349 08374, January 6, 1976;
- E 2385 08371, February 11, 1976.

The choice of the reserved dates was motivated by the idea of comparing the landscape observed in 1972 - 73, during the year of the great Sahel drought, with the same landscape observed under normal rainfall conditions.

Analysis of these data will result in the publication of dichronic maps placing in evidence the multiseasonal multiannual variations such as those resulting from environmental conditions and from human actions.

The photometric parameters are the following.

4.2.1. Image E 2259 08384, October 9, 1975
(coded FOR 4)

- Geographical coordinates of the center: 11°32 N, 14°41 E.
- Geographical coordinates of the nadir point: 11°32 N, 14°45 E.
- Solar elevation: 53°.
- Solar azimuth of the radiometer: 116°.

4.2.2. Image E 2349 08374, January 6, 1976
(coded FOR 5)

- Geographical coordinates of the center: 11°32 N, 14°35 E.
- Geographical coordinates of the nadir point: 11°31 N, 14°38 E.
- Solar elevation: 40°.
- Solar azimuth of the radiometer: 133°.

4.2.3. Image E 2385 08371, February 11, 1976 /19
(coded FOR 6)

- Geographical coordinates of the center: 11°33 N, 14°33 E.
- Geographical coordinates of the nadir point: 11°30 N, 14°35 E.

- Solar elevation: 42°.
- Solar azimuth of the radiometer: 122°.

4.3. NOAA data on Chad

4.3.1. Choice of dates

Chad is overflown by the NOAA meteorological satellite every 12 hours with recording in the morning (Figure 4.B). With a view to thermographic cartography of Chad, ten images have been recorded on the descending node between 0720 and 0815 by choice on those days in the months of June and July, 1977, on which the axis of the trajectory was located between 6°00 east and 22°00 east at a recording latitude of 12°1 north.

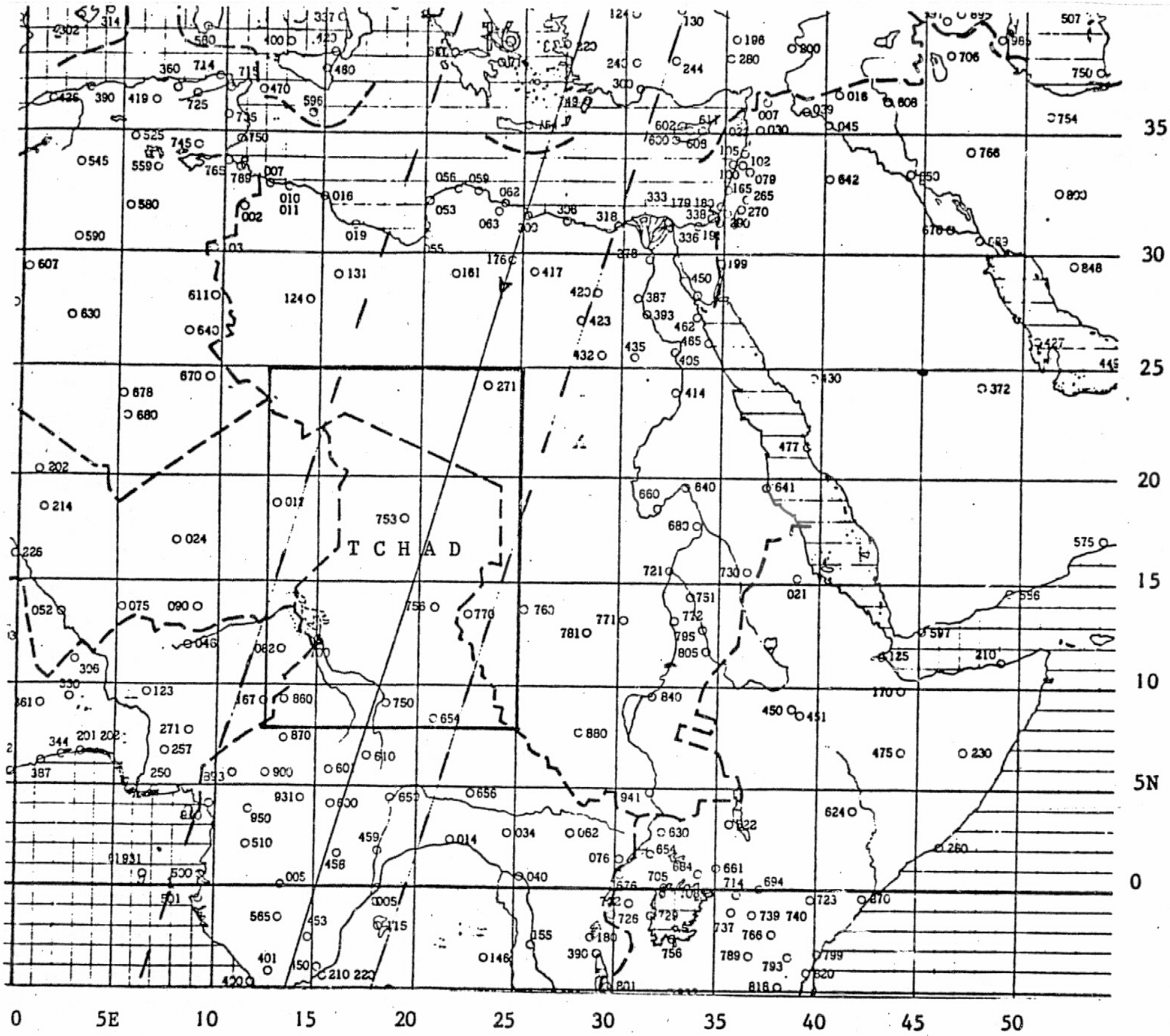
The recording was carried out by the APT (Automatic Picture Transmission) station of the ASECNA at N'Djamena on analog tapes. The analog tapes digitized at C.E.M.S. at Lannion permitted the choice of the following dates:

- orbit NOAA 5 - 3857, June 6, 1977:
  descending node: 7 h 43'26", 13°98 E,
  recording: 12°1 N, 17°6 E.

- orbit NOAA 5 - 3882, June 8, 1977:
  descending node: 8 h 11'52", 6°88 E,
  recording: 12°1 N, 10°5 E.

- orbit NOAA 5 - 3894, June 9. 1977:
  descending note: 7 h 27'54", 17°88 E,
  recording: 12°1 N, 21°5 E.

- orbit NOAA 5 - 3919, June 11, 1977:
  descending node: 7 h 56' 193 [sic], 10°78 E,
  recording: 12°1 N, 14°40 E.



Source: A S E C N A

Figure 4.B. Chad: Orbital traces of NOAA 5 recorded in June, 1977 (N'Djamena APT Station)

- orbit NOAA 5 - 3956, June 14, 1977:
  descending node: 7 h 40'45", 14°67 E,
  recording: 12°01 N, 18°30 E.

- orbit NOAA 5 - 3981, June 16, 1977:
  descending node: 8 h 09'09", 7°57 E,
  recording: 12"1 N, 11°20 E

4.3.2. Characteristics of the NOAA data /21

The distance between N'Djamena and the Equator along a projection of the orbit on the ground being about 1,387 km, the difference between the time of passage over the nadir and the time of the descending node is about 4' (mean velocity at an altitude of 1510 km is 7.5 km/sec).

The analog tape recorded at the N'Djamena APT station (ASECNA) was digitized at the C.E.M.S. under the following conditions:

- Rate of sampling: 1000 points per second.

- Number of points per line in the scan: 1250 points; the useful portion of the signal corresponding to the effective scan at the Earth's surface involves 625 data points among the 1250 points corresponding to a complete revolution of the radiometer mirror. These 625 points cover a scan width of about 1500 km.

- The reolution of the digitized image in the morning is 7.54 km along the scan and 7.32 km along the trajectory (course of the satellite).

- The period of rotation of the satellite is 116 minutes, 20 second.

- The pick-off channels correspond to the following spectral bands:

Figure 4.c. Image produced by visible bands (0.5 - 0.7 μm of the NOAA 5 satellite. The data received at N'Djamena on 8 June 1977 relate to the north part of Central Africa. Lake Chad appears as a dark patch in the lower part of the image.

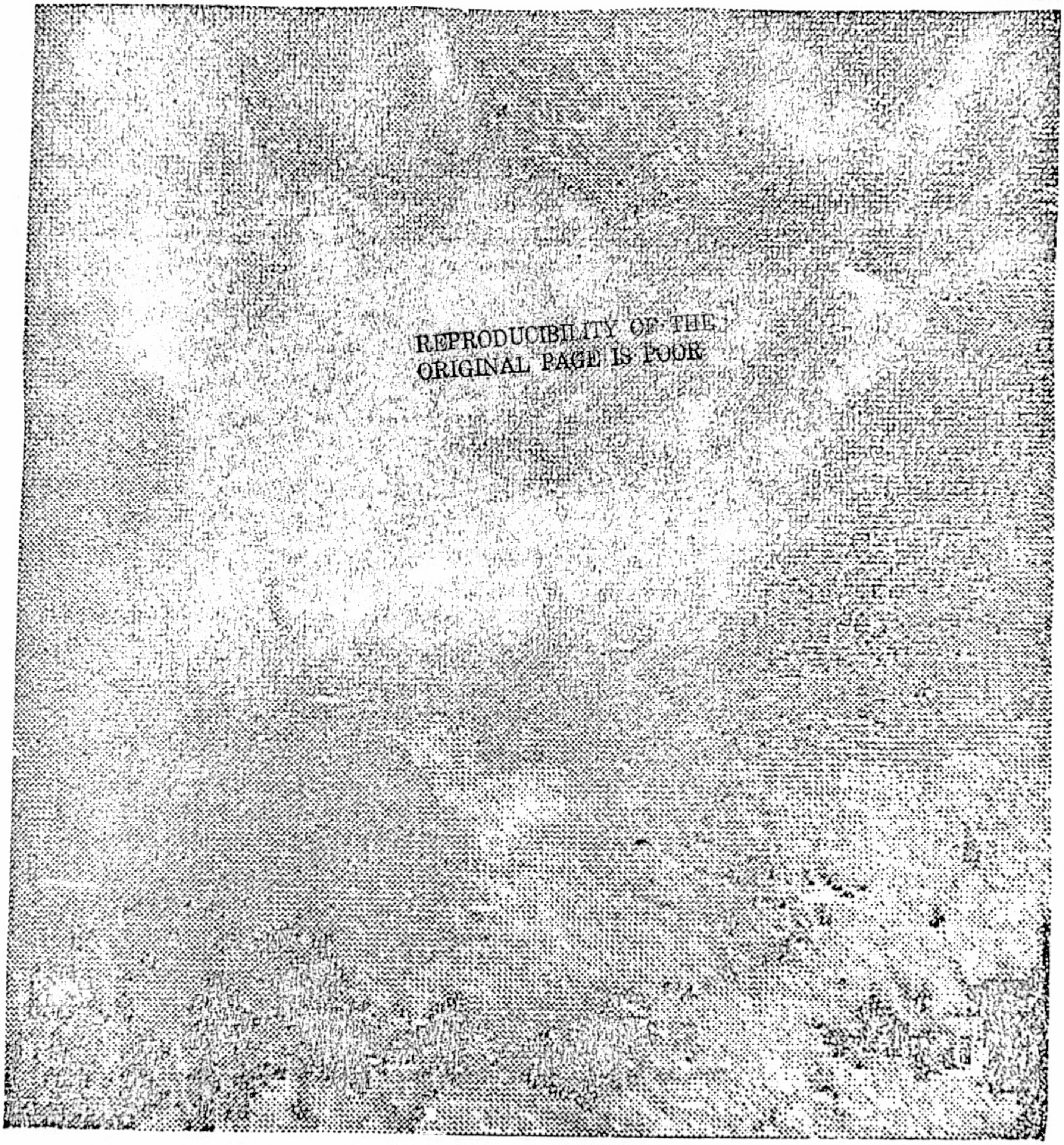


Figure 4.D. Image produced by the thermal infrared band (10.5 - 12.5 μm) by the NOAA 5 satellite. This enlargement shows the region of Lake Chad and that of N'Djamena

- in the visible: 0.52 to 0.73 microns almost retrieving channels MSS 4 and MSS 5 on LANDSAT,
- in the infrared: 10.5 to 12.5 microns.

We show in Figures 4.C and 4.D examples of the printout of the NOAA 5 data on the printer-plotter at CTAMN.

CHAPTER 5 - AUTOMATIC CLASSIFICATION PROCESSING WITH FOR 1, FOR 2, FOR 3 AND FOR 1.2

5.1. Utilization of the FRACAM system /24

The classification system developed by CTAMN provides the following functions:

- spectral display and statistics (FRAC 1),
- homologous analysis (FRAC 2),
- classification in ascending order (FRAC 3),
- combining around changing features.

FRAC 1 provides a general function of display on a TEKTRONIX display console allowing the edition of a certain number of images and statistical results so as to facilitate the dialogue between users of the classification system. This step is particularly important at the time of the determination of the cutting out of the histograms adapted to the study themes, as well as at the moment of the spectral coassociation with the classification system. This last phase thus allows one to decide on the pursuit of the cutting out of spectral classes, the taxonomic significance of which appears very confusing to the user.

FRAC 2 allows, by means of homologous analysis, the determination of a sub-space for representing the binary data associated with the cutting out of the histograms. This program follows from an ascendant hierarchical classification of slices across the channels (FRAC 3) in which the role is to show up the correlations able to exist between the channels at the level of the most significant spectral signatures. The interactive interruption of the classification tree determines the number of spectral classes and decides on their characterization by the slices of the channels which are the most correlative with them.

FRAC 4 develops the final phase of the classification by association of each pixel to the spectral class to which it is the closest. The results are then displayed and critiqued by the renewed use of FRAC 1, thus permitting the interpretation of each spectral class as a function of the geographic classes on the display console.

This last step of the geographic and taxonomic post-association allows the conduct of the refinement of each of the groups as a function of the theme being treated. This approach, called classification stepping is carried out by reiteration of FRAC 1 - FRAC 4 all together in adapting the statistical parameters used to taxonomic sub-groups which the user wants to discriminate.

5.2. Data coding /25

In order to provide for a degree of acuity sufficient for the choice of integrations among the spectral bands, the processing takes place by a transformation of the measurements recorded by the MSS radiometer.

This transformation, called disjunctive encoding, is fully connected with the technique of photoprocessing by equidensities. In effect, such a coding is carried out by associating with each physical value a binary code corresponding to the portion of the values (or level of gray scale) in which it is included.

Thus, with each slide of the histogram, there is associated a binary image which, in the methods of colored equidensities, corresponds to a particular color of the pallette being employed. With each slice of the order i, there is associated a relative frequency P_i:

$$P_i = \frac{\text{surface covered by the portion of the values } i}{\text{total surface of the image}}$$

The choice of the cutting is obviously the preponderant control parameter as far as the effectiveness of the corresponding coding is concerned. If, a priori, none of the information is available in the cartographic area, the choice will perhaps be guided by the information

theory of Shannon. In this setting, one can characterize the quantity of information of a disjunctive coding by the magnitude H:

$$H = - \sum_{i=1}^{N} P_i \log_2 P_i$$

where N = number of groups cut. This criterion is maximum when all the P_i are equal to 1/N or where, to put it the same way, all the binary images are the same surface. This is the case when the cutting takes place at groups of isopopulation; one would then get:

$$H_{max} = \log_2 N$$

where N = number of groups cut. The quantity H is not, however, a mean criterion which is maximized in the case of cutting into isopopulations, despite the quite particular significance associated with a group of particular value.

Thus it is that the DUERB program offers, from the selection of data, a cutting into isopopulation of each of the histograms corresponding to the spectral bands MSS 4 to MSS 7. Thus, for the area FOR 3 (Figure 5.A), the list of the parameters for selection is followed by a graphic presentation of each histogram (Figure 5.B), accompanied by an appropriate slicing.

Individually at the level of each binary image of frequency P_i, the preceding criterion can appear to be of little significance. Association with the spectral quality can thus be practiced in adapting the cutting to the level of taxonomy desired. If one looks at the group of histograms corresponding to FOR 3 (Figures 5.C to 5.F), the coding in isopopulation slices can appear acceptable for the MSS 4 and MSS 5 spectral bands. On the other hand, the pronounced multimodality of the MSS 7 histogram leads to an adjustment of the cutting. /28

	Cutting of channel MSS 7									
Isopopulation	2	15	18	20	21	22	23	24	25	63
Adjusted	2	6	12	15	18	20	22	24	26	63

TAPE IDENTIFICATION

FRAME IDENTIFIER 1173-0851300
TAPE NUMBER 3
LENGTH RECORDED 3296
NUMBER OF POINTS PER LINE 810
ADJUSTED LINE LENGTH 3240

DATE OF FRAME ACQUISITION 12 JAN 73
COORDINATES OF PHOTO CENTER
LATITUDE C 411-30
LONGITUDE /E014-40

a. LANDSAT characteristics in Zone 3

ORDER OF FIRST POINT TO PROCESS BY LINE - IPDEB - 280
ORDER OF LAST POINT TO PROCESS BY LINE - IPFIN - 539
NUMBER OF POINTS OMITTED NPSAUT- 0

START LINE - LDEB - 193
END LINE LFIN - 343
NUMBER OF LINES OMITTED NLSAUT - 0

NUMBER OF ISOPOPULATION LEVELS NBNIV - 10

NUMBER OF POINTS READ NPTS - 39260

NUMBER OF POINTS PER LINE NPLIG - 260

b. FOR 3 parameters for data selection

Figure 5.A. List of parameters of the DUERB program for the FOR 3 area

The adjustment is used for successive visualization of each binary image on the display console, so that the taxonomical significance can be evaluated.

5.3. Homologous analysis of the image

The preceding coding allows the conversion of the initial set of data into a binary set in which one studies the structure with respect to the similarity which can exist between the binary images.

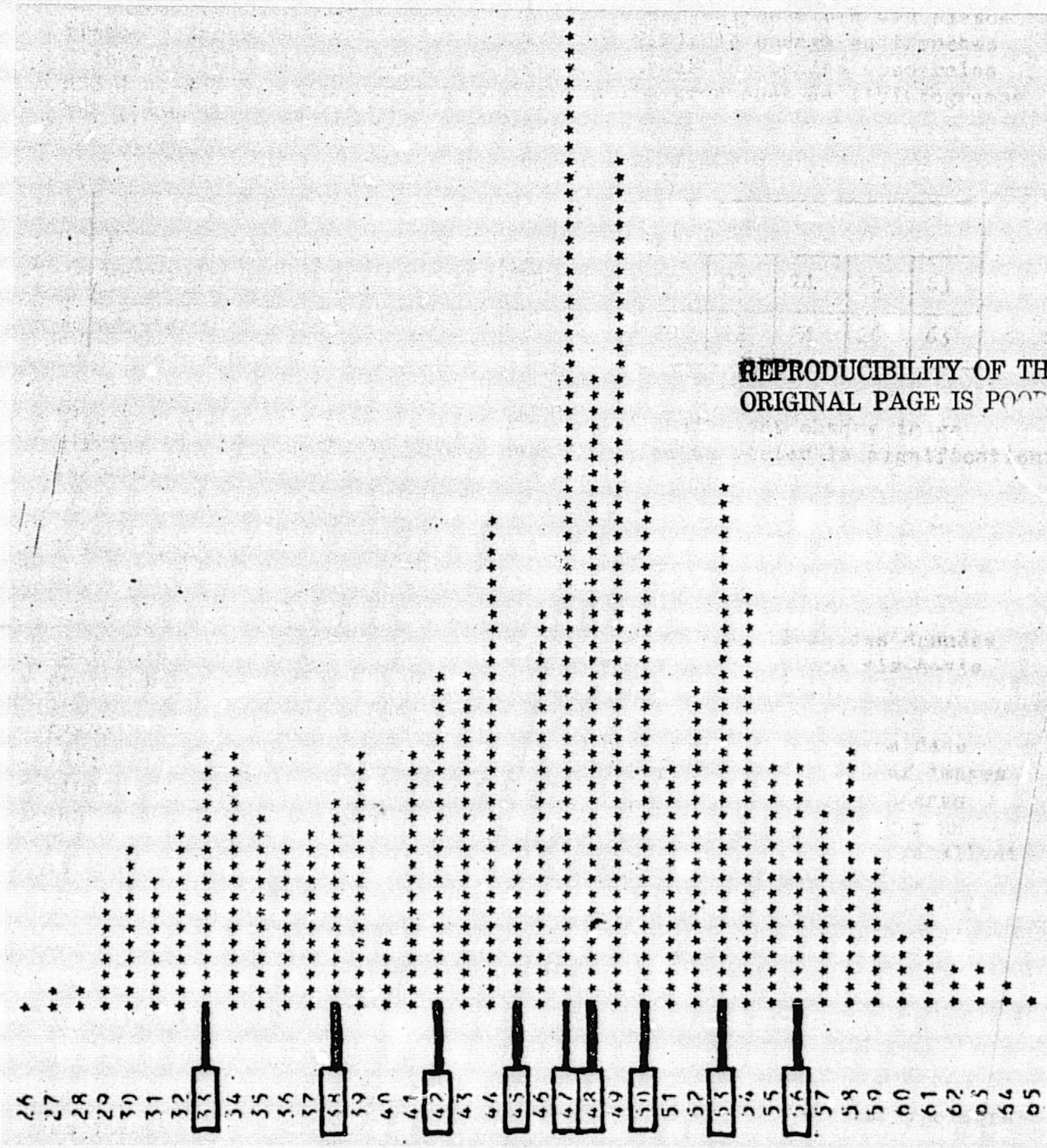


Figure 5.B. Histogram of channel MSS 4 for FOR 3 area. The values in the boxes correspond to levels of cutting out of isopopulations

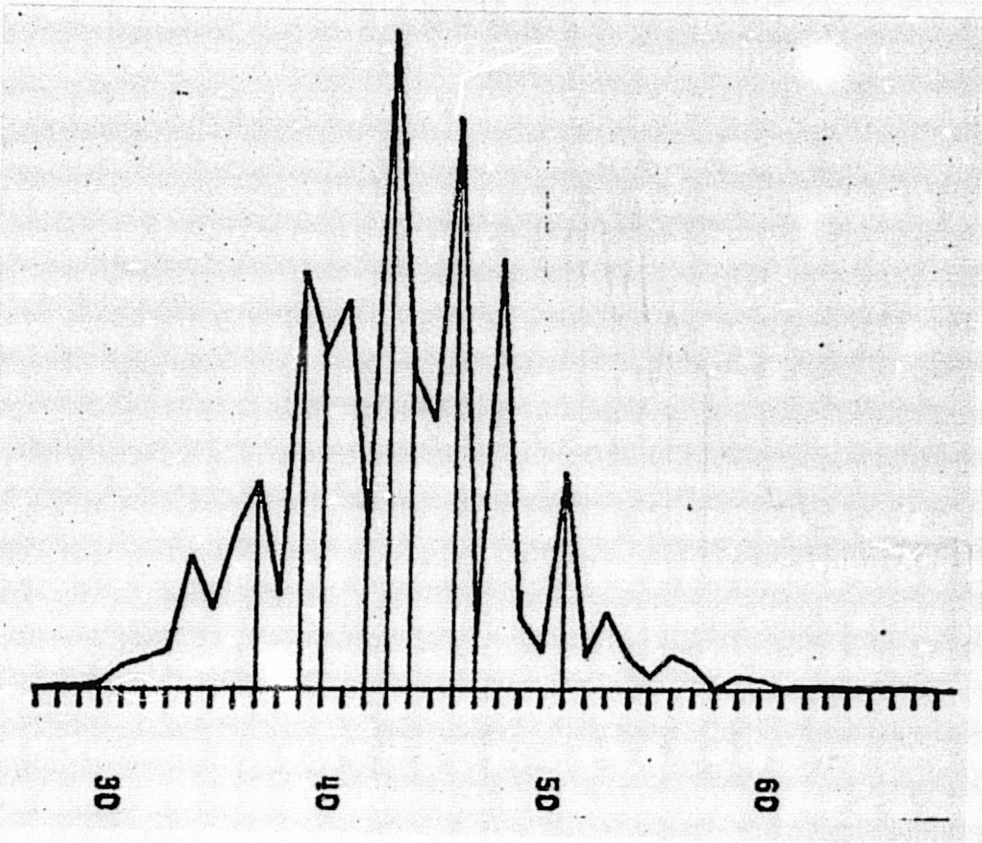


Figure 5.C. Histogram of channel MSS 4 (0.5 - 0.6 μm) for FOR 3 zone

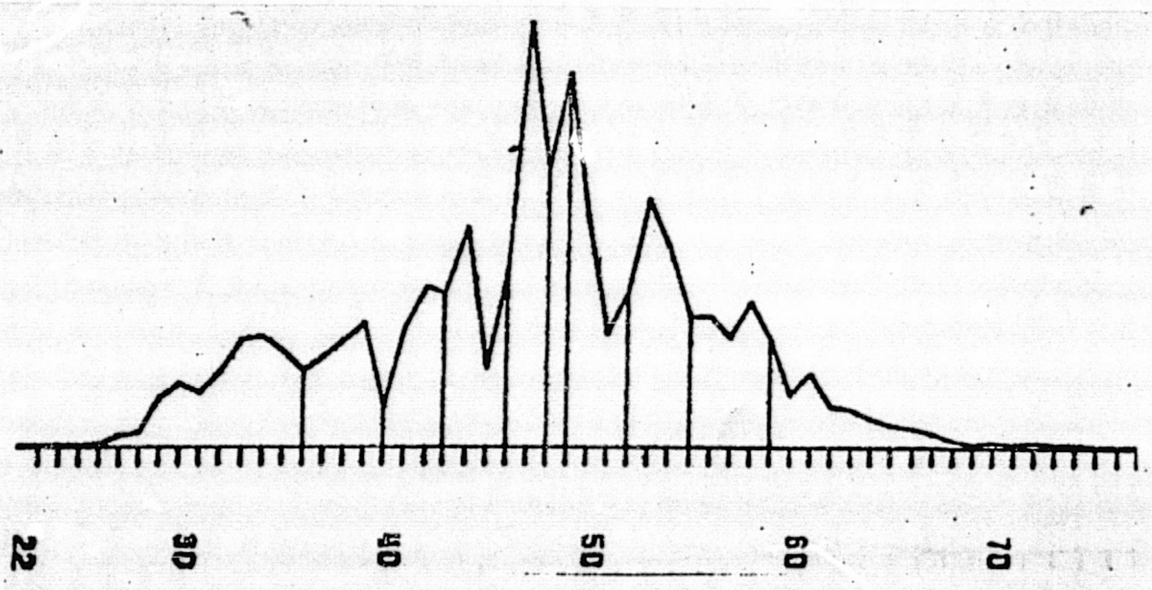


Figure 5.D. Histogram of channel MSS 5 (0.6 - 0.7 μm) for FOR 3 zone

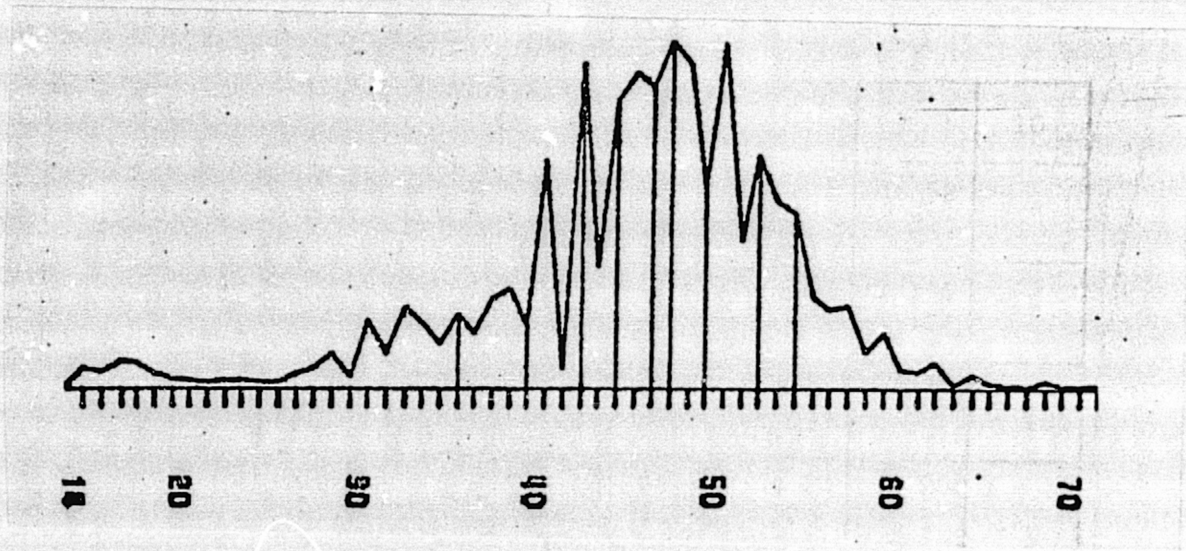


Figure 5.E. Histogram of channel MSS 6 (0.7 - 0.8 μm) for FOR 3 zone

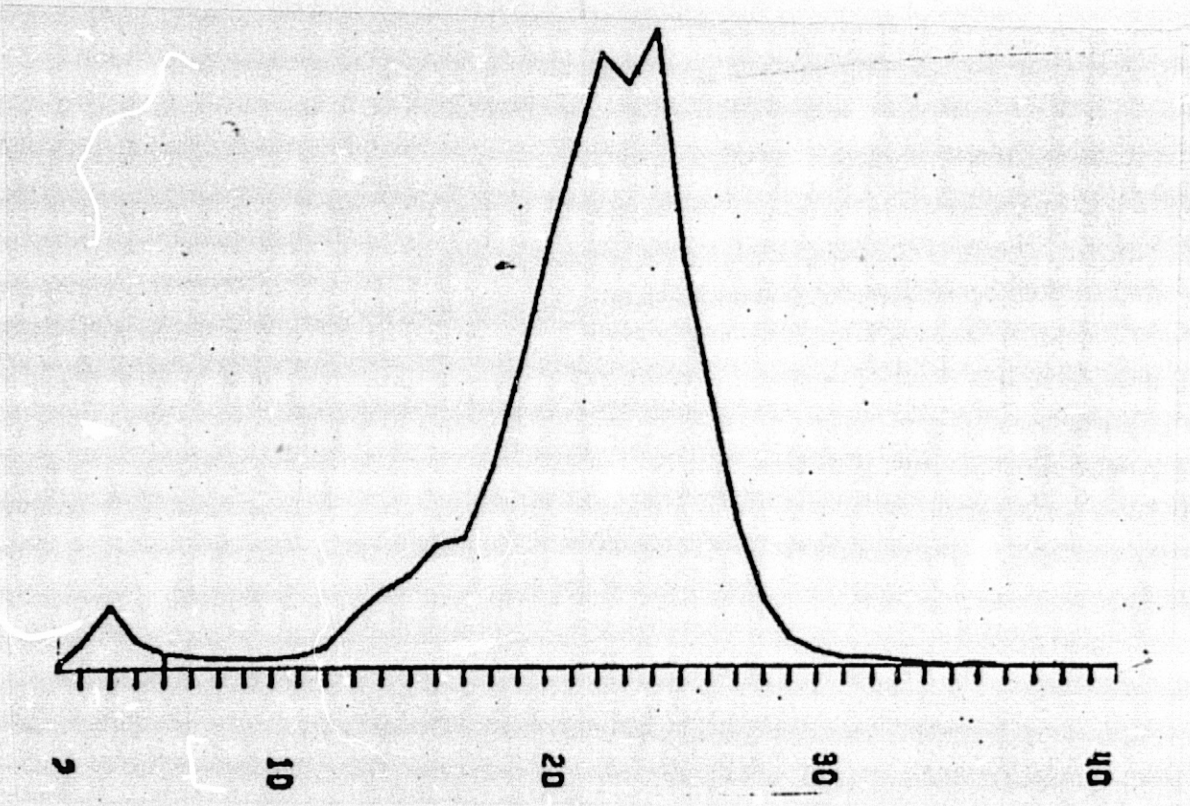


Figure 5.F. Histogram of channel MSS 7 (0.8 - 1.1 μm) for FOR 3 zone

Homologous analysis offers us plane plots in which each binary image is represented by a point. Two binary images are all the more alike, the closer together the corresponding points are. Each image (or each point) is tagged with a letter/number code made up of one letter and one number. The letters from A to D correspond to the spectral band going from MSS4 to MSS 7. As for the number, it indicates the order of the value slice associated with the binary image. The codes corresponding to FOR 3 are indicated in Table 5.G.

5.4. Determination of the groups

The phase is that of the homologous analysis and the printout of the binary images.

The determination of the groups which are most characteristic from the standpoint of their taxonomic significance takes place in two stages. The classification tree of images in hierarchical ascendancy (Figure 5.H) is cut at a constant diameter and one thus visualizes the groups which are formed (the visualization is at the 1/100,000 scale on the display console, then out to the printer-plotter). Then, the study of the parameters for control of the assembly

TABLE 5.G. SLICES OF VALUES CORRESPONDING TO THE NUMBER-LETTER CODING USED IN THE FOR 3 ANALYSIS

	1	2	3	4	5	6	7	8	9	10
(A) MSS 4	from 6 to 32	from 33 – 35	from 36 – 37	from 38 – 39	from 40 – 41	from 42 – 44	from 45 – 47	from 48 – 51	from 52 – 82	
(B) MSS 5	from 22 – 30	from 31 – 35	from 36 – 41	from 42 – 44	from 45 – 47	from 48 – 50	from 51 – 56	from 57 – 61	from 62 – 104	from [illegible]
(C) MSS 6	from 14 – 21	from 21 – 29	from 30 – 36	from 37 – 39	from 40 – 44	from 45 – 47	from 48 – 50	from 51 – 53	from 54 – 56	from 57 – 108
(D) MSS 7	from 2 to 5	from 6 – 11	from 12 – 14	from 15 – 17	from 18 – 19	from 20 – 21	from 22 – 23	from 24 – 25	from 26 – 63	

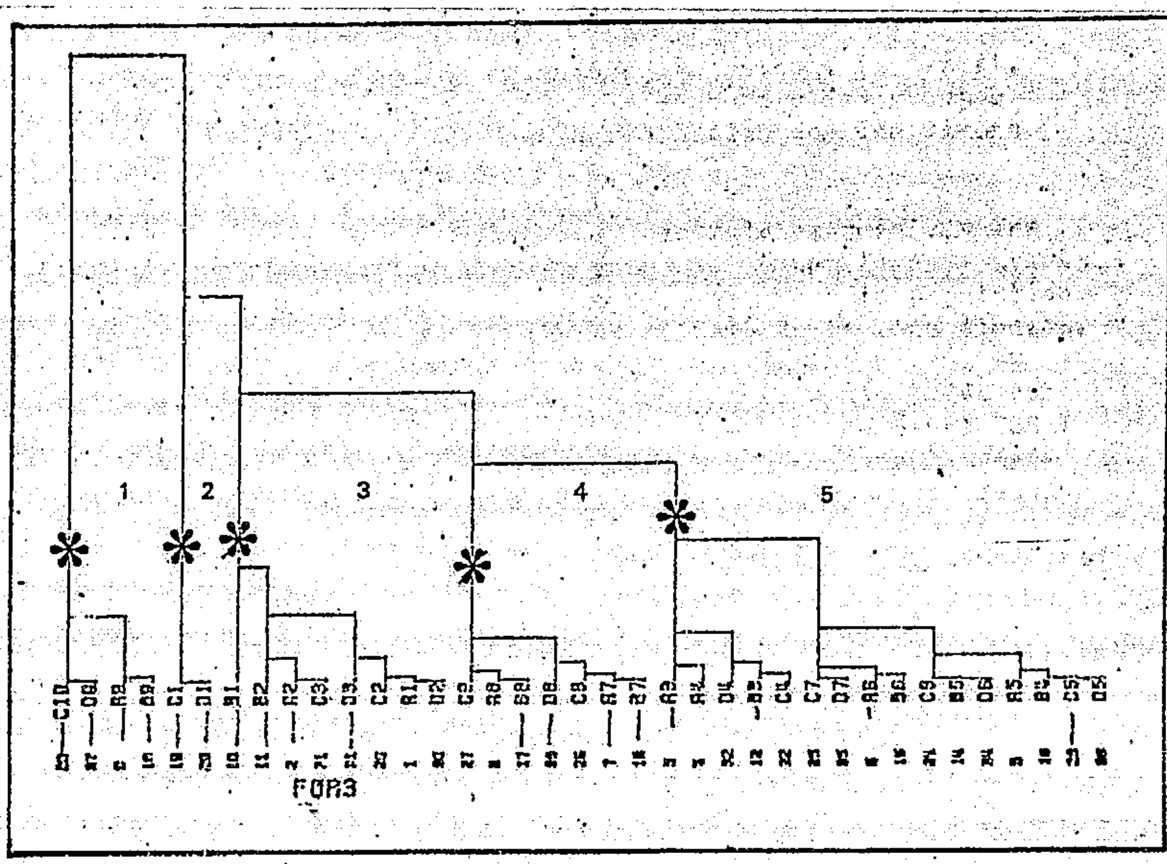


Figure 5.H. Ascendant hierarchical classification tree for binary images

of and the identification of known objects in the different classifications allows one to go by successive steps from the uncontrolled combinations to controlled combinations by means of spectral support (identification of the spectra of known objects) and taxonomic support. One ends up with a classification tree and with groups, the taxonomic significance of which is certain. /3

The process of descending classification has been retained. It permits also, by successive iterations, procession to the cutting into groups as removed as possible from the function of the recognition of different objects characterizing the taxonomy.

From division to division by utilizing the spectra used on the statistical parameters of the signatures, one arrives at a legend having the most discriminating geographic significance possible within the population of pixels (elementary slices of LANDSAT imagery) in the zone studied.

In particular, the criteria for the cutting of the groups are based on the form of the histogram of luminance values in channel MSS 7 with, in certain cases, control in MSS 4 and MSS 5. For example, for the vegetation the effect of the chlorophyll function is interpreted by a small maximum in the bell curve of the spectral statistics at about 550 nanometers (MSS 5) and a large maximum between 800 and 1300 nanometers (MSS 7).

To demonstrate the significance of the spectral statistics of the groups, the conversion of the levels of reflectance of the different channels into luminance values has been effected according to the following table of cross-references:

LANDSAT channel	Wavelengths	LANDSAT code, volts	Correction factor
MSS 4	500 to 600 nm	0 to 127	0,195
MSS 5	600 to 700 nm	0 to 127	0,157
MSS 6	700 to 800 nm	0 to 127	0,138
MSS 7	800 to 1100 nm	0 to 63	0,730

The energy recorded in this case is measured in $W.m^{-2}.sr^{-1}$.

5.5. The readout of the spectral statistics of the group

The FRACAM system offers us a certain number of statistical results which can be:

- the limits of all the disjunctive coding:

example in group 9 of FOR 3: /34

channel 4 — 30, 39, 41, 43, 60
channel 5 — 22, 39, 42, 45, 48, 104
channel 6 — 14, 42, 45, 48, 108
channel 7 — 2, 19, 21, 23, 40,

- the control parameters of the assembly:

  example in FOR 3:

  class 91 - A1, B1
  class 92 - C1, D1,

- a group/channel cross reference table which one can read out on the printer-plotter;

- the spectral statistics for the groups:

  example in FOR 3:

  class 91

	MSS 4	MSS 5	MSS 6	MSS 7
Pixel mean value	39,24	41,72	45,29	21,77
Std. deviation	1,25	2,63	2,07	1,29

  class 92

	MSS 4	MSS 5	MSS 6	MSS 7
Pixel mean value	41,68	45,09	43,44	19,76
Std. deviation	1,54	2,13	1,69	1,02

- graphic readout of the groups in the form of scale-less automatic cartography according to the graphic symbols chosen in the print channel of the computer.

Graphic readout and output from the printer-plotter are possible at each of these stages.

CHAPTER 6. PROBLEMS OF IMAGE GEOMETRY

6.1. Geometric corrections of LANDSAT images (EROS format)

LANDSAT images are contaminated by a certain number of geometrical distortions, of which the most important is caused by the rotation of the Earth during the period of time in which the frame is being received ($\simeq$ 28 sec). /35

This phenomenon gives rise to two types of distortion:

- a geometric displacement of lines from the right to the left;
- a stretching out of the image in the direction from top to bottom.

After analysis, it appears that one can ignore the other types of deformation (curvature of the sweep lines, enlargement of the pixels which are at a distance from the nadir point), their magnitude in most cases being of an order equal to the pixel itself.

6.1.1. Line displacement (deformation of the parallelogram)

The fact that the Earth turns during the acquisition of an image is troublesome to the extent that the system of synchronization in which we have to work is not fixed. Figure 6.A shows by way of example the distance BC, giving the maximum distortion due to the rotation of the Earth during the 28 sec of the image acquisition or 0.11 degrees, which gives 13 km at the Equator.

A Canadian publication* allows us to formulate the problem.

*Cartographic accuracy of ERTS. Dr. V. Kratky. National Research Council of Canada, Ottawa, Canada. KIAOSI.

One finds:

$$\omega = C\sqrt{\sin^2 i - \sin^2\phi}$$

where i = orbital inclination of the satellite (i = 99);

ϕ = latitude of point A;

C = constant (1/13.9) connected with the speed of movement of the satellite.

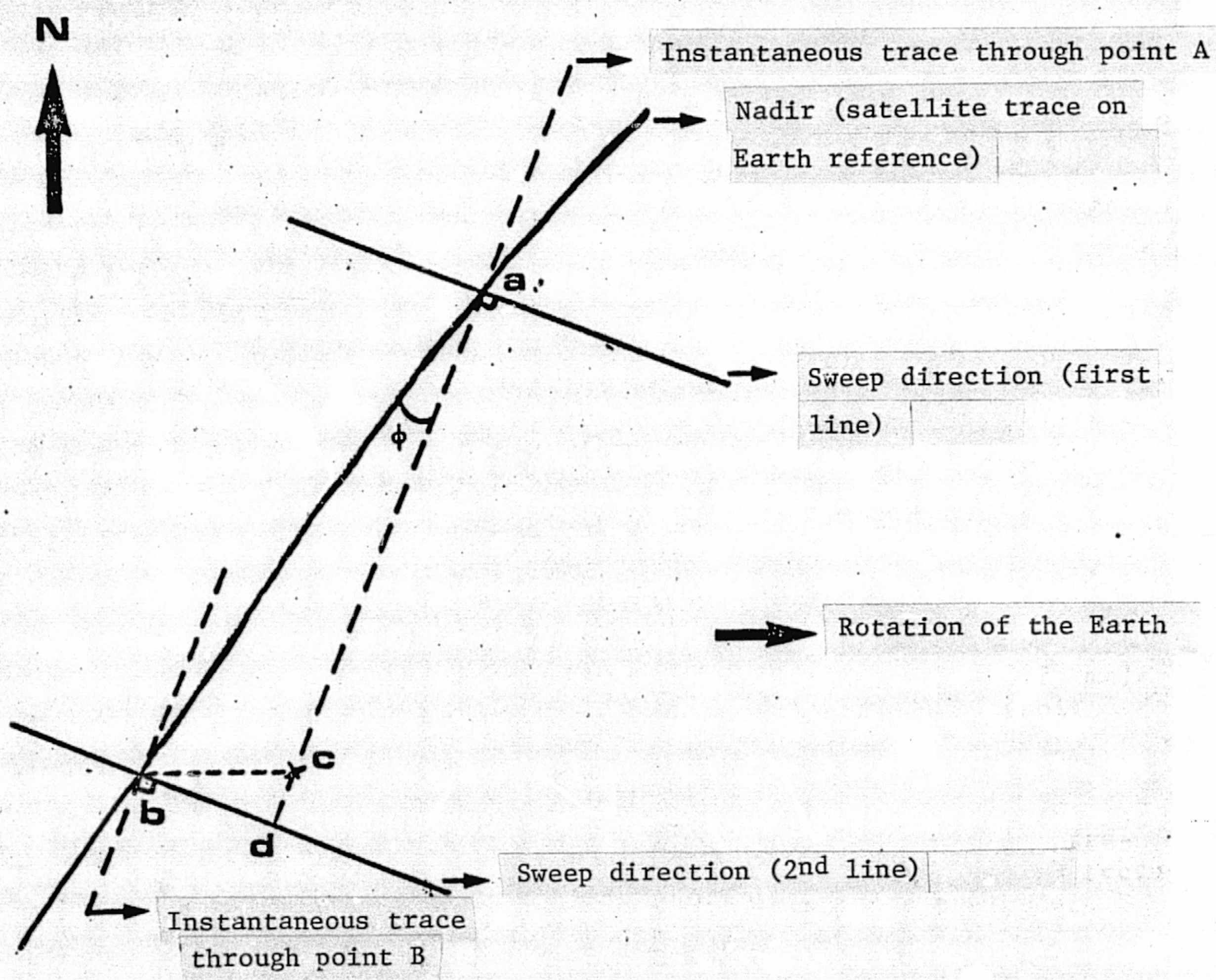


Figure 6.A. Representation of the deformation of a parallelogram due to the rotation of the Earth

6.1.2. Stretching out the image in latitude /37

This distortion is the direct result of the deformation of the parallelogram.

If the Earth had not moved during image acquisition, point B would get position C (Figure 6.A). Under these conditions, the image stretch out is the amplitude $\overline{DC}$.

One finds: $\overline{DC} = \overline{AC} \times C \times \sin(i - \pi/2)$.

AC is the coarse height of the image (185 km), and C is the constant defined above (1/13.9). It is noted that this quantity $\overline{DC}$ is a constant value = 2.04 km.

6.1.3. Generation of the image on the VERSATEC printer

On the VERSATEC printer, each pixel is represented by a rectangle of 4 x 6 VERSATEC units (i.e., 0.5 x 0.75 mm) for a scale of 1/100,000, and 8 x 12 units (i.e., 1 x 1.5 mm) for the scale of 1/50,000.

Under these conditions, it is necessary to begin with to have an image reformatted such as to get pixels representative of a surface of 50 x 75 meters. This work is performed at the same time as the distortion correction analysis above.

6.2. An experiment in marking the LANDSAT image with a mirror*

An experimental mirror (Plate B) has been installed at the Science Institute in N'Djamena** (April, 1977). Two sightings were

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*The experiment is based on that of W. E. Evans, described in "Marking LANDSAT Images with Small Mirrors Reflectors" in NASA Earth Resources Survey Symposium, Houston, Texas, June 1975, Vol. I.B, pp. 1185-1196.

**The experiment was carried out in collaboration with J. P. David, Professor of Chemistry, Dean of the Science Faculty at the University of Chad, and Leandri, maintenance engineer at the Science Institute. The position of the mirror was directed by G. Doublier, geometrist and Professor of the E.N.T.P. at N'Djamena.

simulated on May 24, 1977 and June 11, 1977, the installation being provided with a temporary mirror.

6.2.1. The observation of May 24, 1977 /39

The data from the simulation are the following:

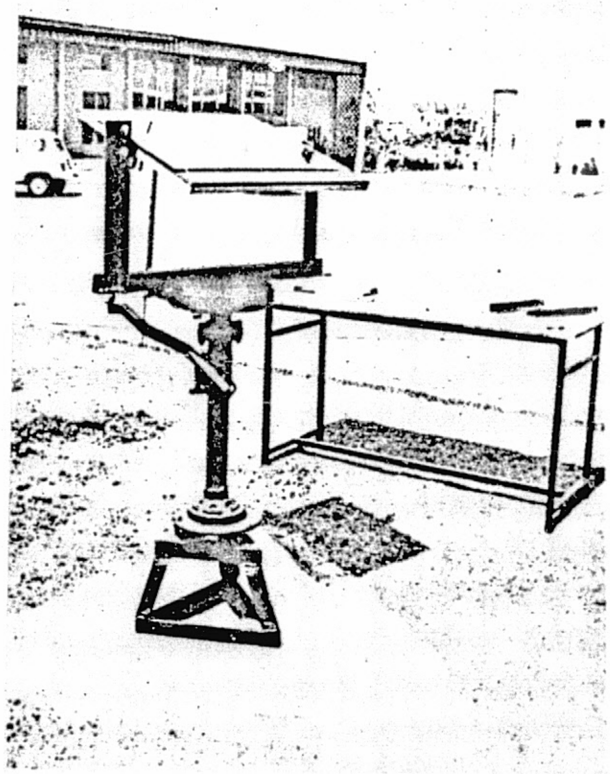
- assumed time of LANDSAT satellite overpass: 8 h 37' 04" UT;
- assumed altitude of the satellite: 912.4 km;
- mirror-satellite azimuth at the moment of the sweep: 304 gr 26692;
- azimuth of the sun at 8 h 37' 04": 78 gr 7453.

6.2.2. The observation of June 11, 1977

The data from the simulation are the following:

- assumed time of LANDSAT satellite overpass: 8 h 37' 04" UT;
- assumed altitude of the satellite: 912.4 km;
- azimuth of the bisector of the satellite-mirror-Sun angle with respect to geographic north: 394 gr 4126
- azimuth of the Sun at 8 h 37' 04" UT: 74 gr 5582

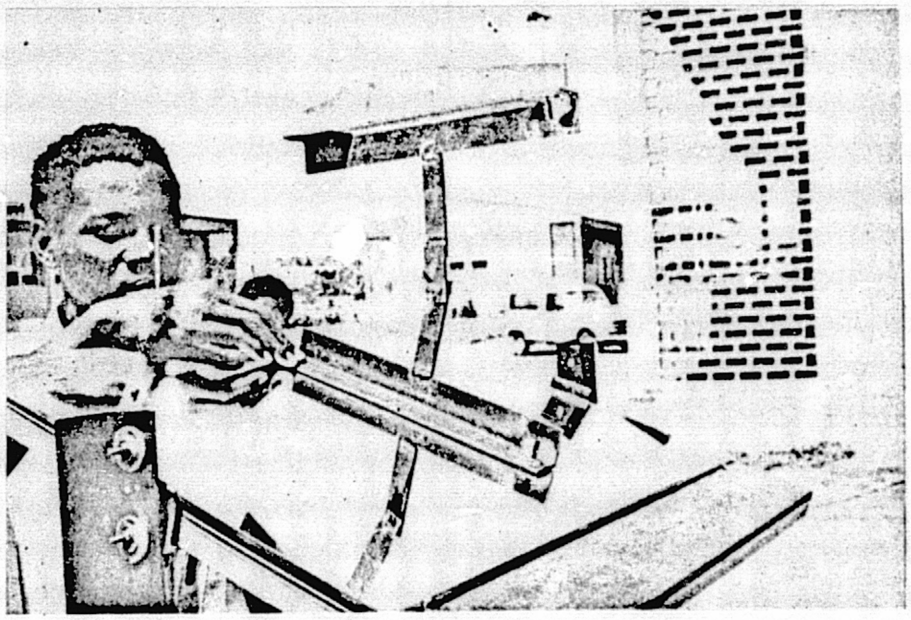
The mirror was installed according to the following co-ordinates:



Mirror for marking LANDSAT images — May, 1977

Plate B. Faculty of Science, University of Chad

(Plate continued on following page)



Positioning of the mirror

Plate B. (continued)

- latitude N: 12° 07' 41',
- longitude E: 15° 00' 11".

6.2.3. Problems posed by the actual observations

To arrive at useful results, the following problems need to be resolved:

a) knowledge of the ephemerides of the LANDSAT satellite;
b) knowledge of the precise altitude of the satellite (varies between 909 and 920 km);
c) acquisition of an aluminum mirror especially polished for the best possible reflectance. The mirror must be slightly convex;
d) the availability of atmospheric refraction measurements and of atmospheric pressure.

CHAPTER 7. GEOGRAPHICAL TAXONOMY

7.1. Ground truth documentation /40

Geographical features were made the object of an inventory in an area 100 km around N'Djamena for which the maximum number of documents were brought together. In particular, they comprised:

7.1.1. Basic topographic maps of the I.G.N.F.

The area studied is covered by the following maps:

- 1/1,000,000 sheets of Fort-Lamy NC 33 and of Garoua ND 33,
- 1/500,000 sheets Lake Chad (Maine-Soroa) and Fort-Lamy,
- 1/200,000 sheets Fort-Lamy ND 33 IV, Makari-Goulfey ND 33 III, Mora NC 33 XXI, Mogroum NC 33 XXII.

7.1.2. Aerial photography of the I.G.N.F.

The area studied is covered by the following flights:

- AE 391/500 - 1971 - March 23, 7 h to 12 h;
- TCH 02/150 - 1972 - March 19, 10 h to 11 h;
- TCH 74 08/200 - 1974 - July 11, 12, 13; 9 h - 12 h;
- TCH 74 - 75 10/500 - 1974 - 1975 - Mogroum sheet, photos 5929 to 6665 on 29/12/74 to 10/1/75, 9 h to 12 h.

7.1.3. Land registry plats

They are of a scale of 1/2,000, 1/5,000, 1/10,000, and 1/20,000.

7.1.4. The soil maps from the ORSTOM exploration

The area studied is covered by the 1/200,000 sheets of J. Pias, E. Guichard, and J. Barbery, dating from 1963. They are the sheets of Fort-Lamy, Fort-Foureau, Mora, and Mogroum.

7.1.5. The geological map of the D.M.G of the A.E.F.

This is an exploration map at 1/1,000,000 laid out by J. Barbeau in 1956 for the D.M.G. of the A.E.F.

7.1.6. Soil data /41

C. Tobias focused on these data in March, 1976, in technical note no. 13, O.R.S.T.O.M. - N'Djamena, "Soil Utilization and Irrigation Capabilities in the N'Djamena Area", 14 pages, mimeo.

7.1.7. Surveys based on ground information and from photointerpretation

These have been put together by C. Bardinet at the Laboratory for Cartography of the University of Chad from 1973 to 1977.

Three types of documents have been used on the ground:

- aerial photographs in I.F.C. and in panchro (N'Djamena Aeroclub) and ground photos in I.R., I.R.C., and panchro taken by C. Bardinet from 1973 to 1977;
- the photointerpretation surveys after the aerial coverage of the I.G.N.F.;
- photointerpretation surveys following the enlargements of LANDSAT image E 2349 08374 of January 6, 1976, enlargements carried out by Gaudin and Husberg at the C.E.R.C.G. of the CNRS using the 1/1,000,000 negative from NASA. These enlargements were prepared, channel by channel, at 1/200,000 and at 1/500,000 for the N'Djamena area. A composite color

photo has likewise been prepared on transparent film at 1/200,000 on Kodalith film (Plates I, J, K, and L).

7.2. Locating the taxonomic subjects

A certain number of features have a pure signature, for example, river waters, bare and dry sands. Other features have a mixed signature, for example, vegetation which may be more or less chlorophyllic, more or less associated with water or with very humid areas, or again the urban areas in the case of which the zonal division into quarters can be marked either by the presence of green areas in the modern residential quarters with villas and gardens, or an earthen habitat (the poto-poto) more or less crowded and with little or no vegetation.

In the test area of around 200 x 200 pixels, the features have been located, and with each feature a certain number of objects have been specifically indentified, the spectral signature of which, by their development through dichronic analysis, should let us refine the support of the classification process.

7.2.1. Pixels, features, and objects

On the LANDSAT digital tape, the features and the objects which they compose are recognized by the form of the levels of mean luminance which is recorded in the 79 m x 79 m pixels, which with overlap would be 79 m x 59 m. The index of the pixels is selected in channel MSS 5 from the photo which is delivered with each tape.

7.2.1.1. The index of pixels FOR 1, FOR 2, FOR 3

- The FOR 1 index (November 1, 1972, strip 3)

  lines 100 to 250,
  1^{st} pixel: 401, last pixel: 659,
  number of pixels read: 39,109,
  number of pixels on a line: 259.

photo has likewise been prepared on transparent film at 1/200,000 on Kodalith film (Plates I, J, K, and L).

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Enlargement of the EROS CENTER 1/1,000,000 negative by MM. Gaudin and Husberg at the photo lab of the C.E.R.C.G. of C.N.R.S. in October 1977. LANDSAT image 2349 08374 of 1/6/1976.

Enlargement to 1/200.000e

Photo 1 - channel MSS5 - 600 - 700 microns

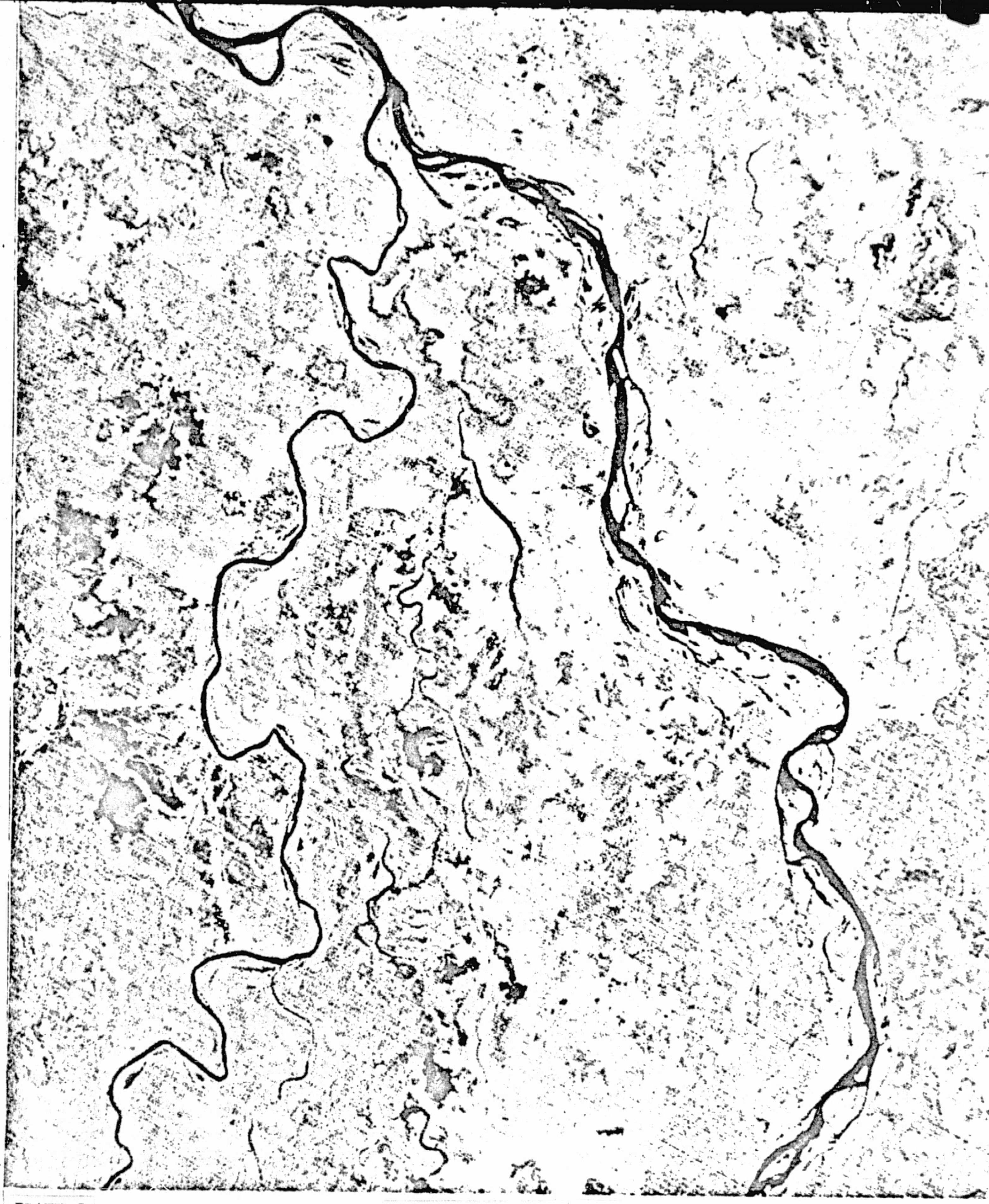


PLATE J

N'DJAMENA AREA

Enlargement of the EROS CENTER 1/1,000,000 negative by MM. Gaudin and Husberg at the photo lab of the C.E.R.C.G. of C.N.R.S. in October 1977. LANDSAT image 2348 08374 of 1/6/1976

Enlargement to 1/200.000e

Photo 2 - channel MSS7 - 800 - 1100 microns

PLATE K

N'DJAMENA AREA

Enlargement of the EROS CENTER 1/1,000,000 negative by MM. Gaudin and Husberg at the photo lab of the C.E.R.C.G. of C.N.R.S. in October 1977. LANDSAT image 2348 08374 of 1/6/1976

Enlargement to 1/50.000e

Photo 3 – channel MSS5 - 600 - 700 m

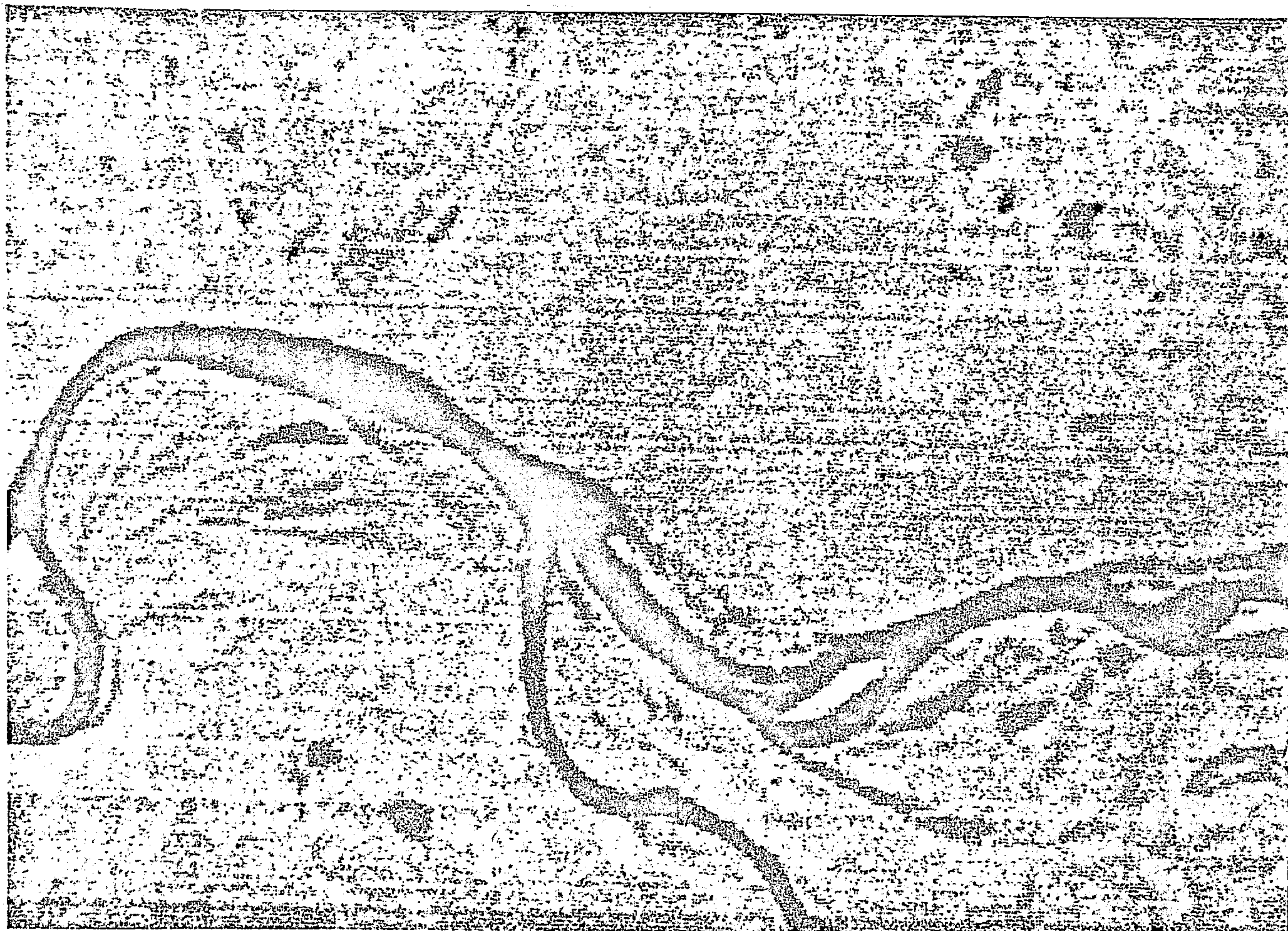


PLATE L

N'DJAMENA AREA

Enlargement of the EROS CENTER 1/1,000,000 negative by MM. Gaudin and Husberg at the photo lab of the C.E.R.C.G. of C.N.R.S. in October 1977. LANDSAT image 2348 08374 of 1/6/1976

Enlargement to 1/50.000e

Photo 4 – channel MSS7 - 800 - 1

• The FOR 2 index (February 17, 1973, str p 3)

lines 354 to 504,
1st pixel: 552, last pixel: 810,
number of pixels read: 39,109,
number of pixels on a line: 259.

• The FOR 3 index (January 12, 1973, strip 3)

lines 193 to 343,
1st pixel: 280, lastpixel: 538,
number of pixels read: 39,109,
number of pixels on a line: 259.

7.2.1.2. The dichronic index for pixels in FOR 1.2

An index of 150 lines and 259 columns has been created in which one takes into consideration the dichronic signature of the pixels of FOR 1 and of FOR 2. The line n and the column m for FOR 1 are superimposed on the line n+254 and column m+151 of FOR 2. This superimposition is possible when all of the indices have received the corrections necessary for them to present the same geometry.

7.2.2. Features and reference objects

7.2.2.1. Alignment of pixel reference

The width of each basic line is 79 m on the ground and the information collected in each spectral band corresponds on the ground to a square of 79 m on a side. The dimension of this basic measuring square is prescribed with account taken of the orbital altitude of the satellite by the instantaneous optical field which is 0.086 milliradians. This optical field which is square in form has the same dimensions for each of the spectral bands MSS4 to MSS 7. /47

The frequency of oscillation of the spin-scan mirror (13.62 Hz) combined with the nominal satellite orbital velocity (6.47 km/sec) assures an almost perfect contiguity of the basic lines at a 79 m width.

This contiguity is not maintained in the direction of the scan. In effect, the signal, having been sampled at 9.95 microseconds, the distance between the measurement sampling points is 56 m.

From this one can infer that the pixels or resolution elements sketch out a regular rectilinear grid (Figure 7.A) on the ground 79 m x 56 m, in which each node is associated with an elementary radiance measurement corresponding to a square of 79 m on a side.

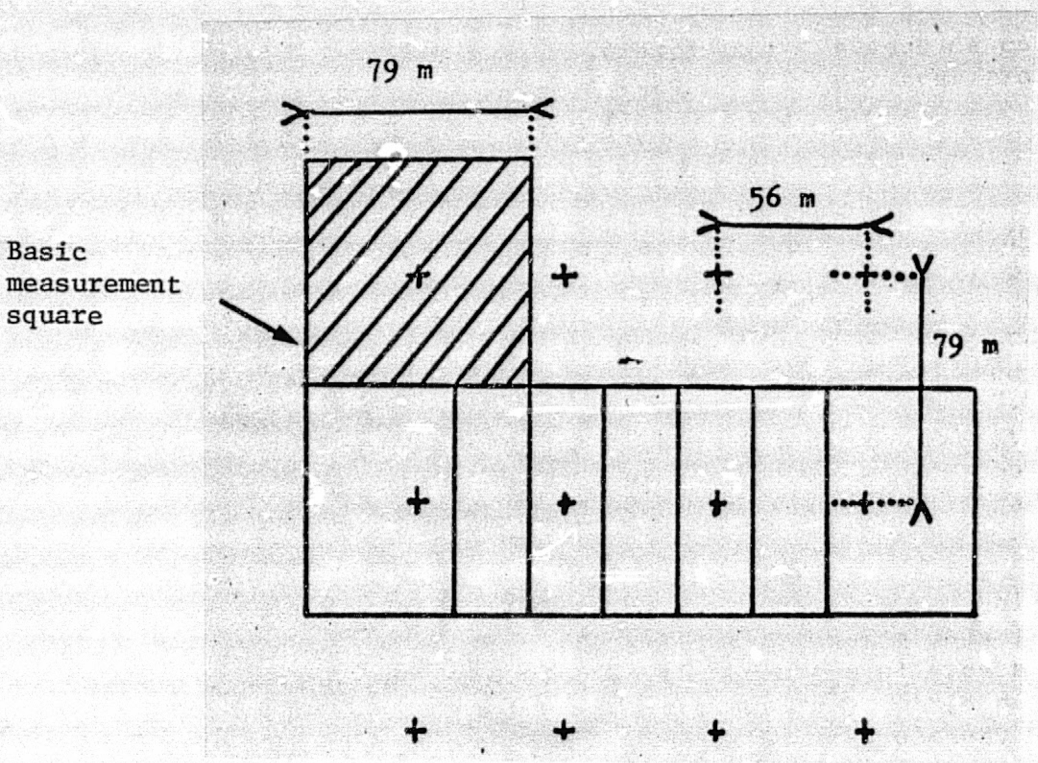


Figure 7.A. Regular rectilinear pixel grid and basic measurement square.

A surface of 1 km^2 is covered by about 224.28 pixels because there are 12.6 pixels per kilometer in the direction of the columns (velocity vector of the satellite) and 17.8 pixels per kilometer in the direction of the scan lines. /48

7.2.2.2. Effective spatial resolution of LANDSAT

To choose the objects marked for identification and locating on the ground, it is important to take into account the limit of the resolution of the MSS radiometer. First of all, it is appropriate to separate two distinct problems which the experimenter can encounter simultaneously:

- the capacity of the MSS radiometer to distinguish two objects of the same type which are located on the ground at a certain distance from each other is essentially concerned with a problem of detection;

- the way in which the MSS radiometer follows the spectral contrasts of the terrain observed and reproduces with fidelity the spectral signature of the objects for the cartographer.

The resolution limits corresponding to each of these problems are quite different. Therefore, we propose to clarify here the concepts which apply to them.

a - Limit of resolution in detection

Conforming to the ERTS Data User Handbook No. 71SD4249, we will confine ourselves to the problem of the detection of a binary terrain feature consisting of three parallel rectangular strips (Figure 7.B-1) following the model of the USAF tri-bar target, 1951. In order that we put ourselves in as realistic conditions as possible, we have chosen terrain features (Figure 7.B-2) consisting in part of objects quite often encountered in the LANCHAD project and enabling an evaluation of the possibilities of detection with the MSS in situations of vegetation/bare earth contrast.

From the point of view of the vegetation, we have chosen both a shrubby carpet of vegetation common in the savanna area and a seeded area of grain field having a growth presenting the mean proportion of vegetative covering corresponding to the cultivation means

/49

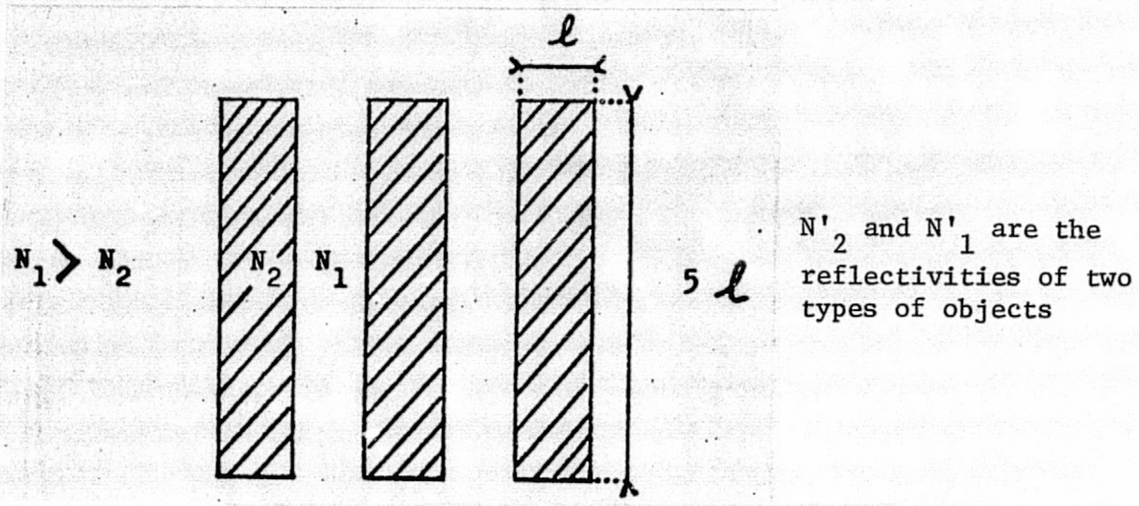
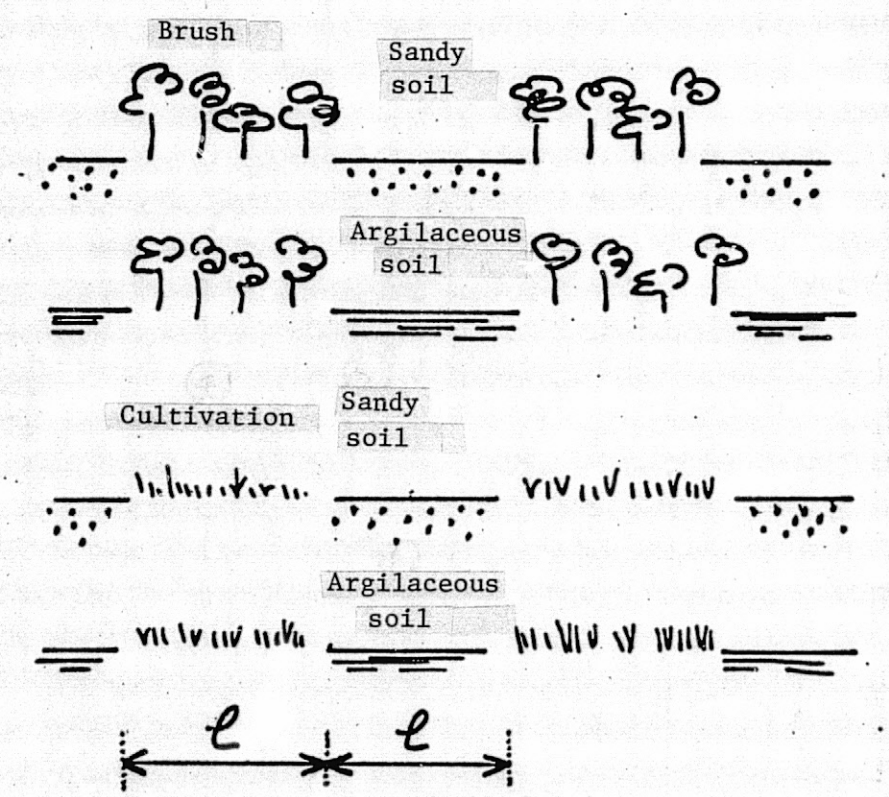


Figure 7.B-1. Model of the binary terrain feature



7.B-2. The four types of terrain features considered

Figure 7.B. Theoretical model used for the estimation of the detection resolution limit of the MSS radiometer

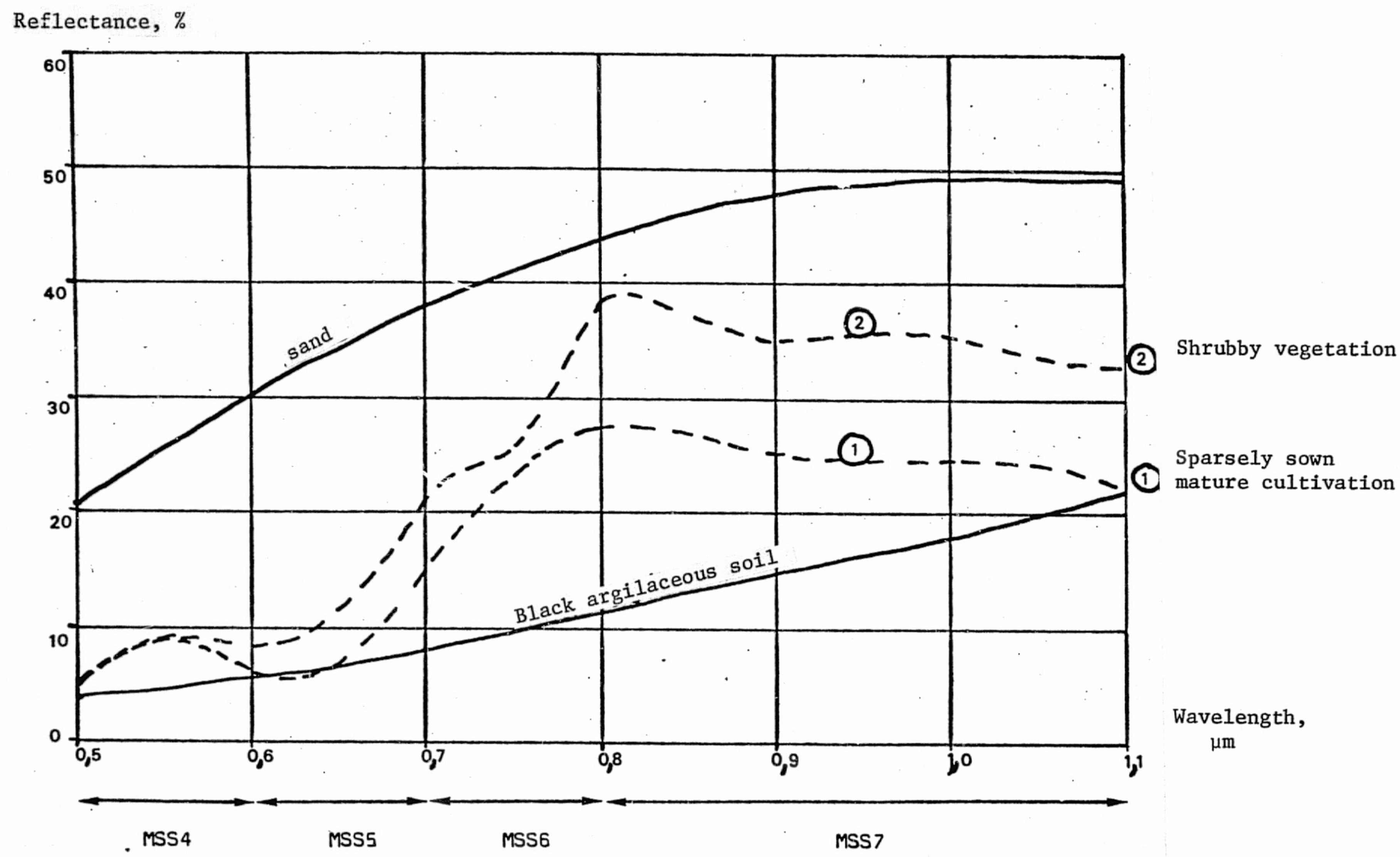


Figure 7.C. Reflectance spectra of some objects representative of the terrain studied by LANCHAD

/50

generally employed in Chad. For the soils, we have retained a sandy soil of strong reflectivity and a wet argilaceous soil of dark color able to represent the areas of alluvial cultivation. The reflectivity spectra of these four objects are presented in Figure 7.C.

In the model presented, a certain number of parameters, depending on the MSS spectral band used, should be considered in determining the limit of the detection resolution; the question is: /52

- $N_1 \ (MSS_i)$ = the reflectivity of the most reflective object in the MSS_i spectral band,
- $N_2 \ (MSS_i)$ = the reflectivity of the least reflective object in the MSS_i spectral band,
- $C_i = \dfrac{N_2 \ (MSS_i)}{N_1 \ (MSS_i)}$ = reflectivity contrast for the MSS_i spectral band,
- $\overline{N}_i = \dfrac{N_2 \ (MSS_i) + N_1 \ (MSS_i)}{2}$ = mean reflectivity

of the terrain feature in the MSS_i spectral band.

Tables 7.D and 7.E present the values and the different parameters for the terrain features obtained, which already enables one to make a certain number of statements concerning the variation of contrasts as a function of the spectral band. One notes that no distinction is possible between crops and argilaceous soils in MSS 5 (0.6 - 0.7 μm), but that, on the other hand, the best contrast is

TABLE 7.D. TABLE OF THEORETICAL REFLECTANCES CORRESPONDING TO THE SPECTRAL BANDS OF THE MSS RADIOMETER

	MSS 4	MSS 5	MSS 6	MSS 7
Sand	25	34	41	46
Black argile	5	7	10	15
Cultivation	9	7	23	25
Shrubbery	9	12	25	35

TABLE 7.E. TABLE OF CONTRASTS (C) AND OF AVERAGE REFLECTIVITIES ($\overline{N}$) CORRESPONDING TO A REGULAR ALTERNATION OF TWO TERRAIN FEATURES. THE CONTRASTS MARKED BY A RECTANGLE RELATE TO THE CASE IN WHICH THE SOIL IS MORE REFLECTIVE THAN THE CROPS

	MSS 4		MSS 5		MSS 6		MSS 7		
	C	$\overline{N}$	C	$\overline{N}$	C	$\overline{N}$	C	$\overline{N}$	
Shrubbery/ sandy soil	2,78	17	2,83	23	1,64	33	1,31	40,5	AS
Shrubbery/ clay soil	1,80	7	1,71	9,5	2,5	17,5	2,33	25	AA
Cultivation/ sandy soil	2,78	17	4,86	20,5	1,78	32	1,84	35,5	CS
Cultivation clay soil	1,80	7	1,00	7	2,3	16,5	1,67	20	CA

obtained in this same band between shrubbery or crops and sandy soil. Concerning the contrast between shrubbery or crops and argilaceous soils it is the MSS 7 channel (0.8 to 1.1 μm) that one should choose. Finally, the exact contrast of a type of an object with respect to a variable natural environment depends greatly on the spectral band employed.

In accordance with the ERTS Data Users Handbook, we will define the detection resolution limit in the width of the strip ℓ, expressed in meters (Figure 7.B-1). The latter at the same time depends on the contrast (C) and the mean reflectivity ($\overline{N}$), and therefore also on the spectral band used. This dependence becomes clear by means of the transfer function (modulation transfer function) and the signal to noise ratio, two mathematical concepts which we will not explain here. However, it is possible to work up graphs giving ℓ as a function of the different parameters C, $\overline{N}$, and MSS_i. We present here two examples of this type of graph.

In the first example (Figure 7.F), the contrast has been fixed at C = 1.8; it is the case of features CS in MSS 7 and of CA or AA in MSS 4. One gets:

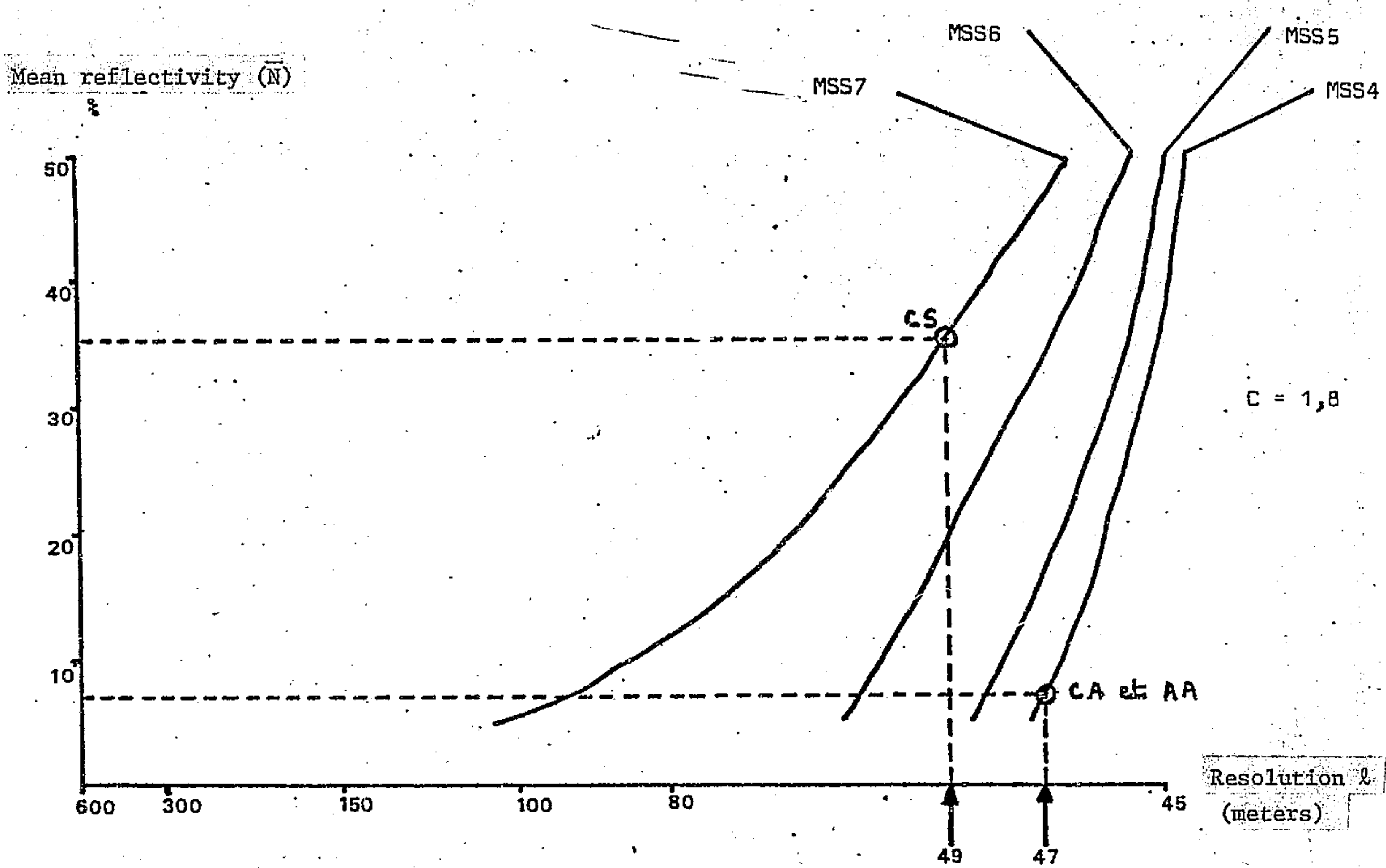


Figure 7.F. Graph giving, for a contrast C = 1.8, the detection resolution ℓ as a function of the mean reflectivity $(\overline{N})$ and of the spectral band MSS_i

/53

$$\ell_{CA} = \ell_{AA} = 47 \text{ m in MSS } 4,$$ /54

$$\ell_{CS} = 49 \text{ m in MSS } 5.$$

These lower resolution limits at 79 m may surprise the reader. It is connected in fact with the optimum capabilities of the system concerning which information theory tells us that the lower limit of resolution is located at $\ell = 49.5$ m, even though the width of the measuring unit is 79 m.

The sampling rate of the signal is a supplementary factor which practically limits the detection resolution to 56 m in the direction of the lines and 79 m in the direction of the columns on the raw data tapes received from the EROS DATA CENTER. However, a theoretical lower limit at one of the two figures given above is an incentive to re-sample the data by interpolating between the pixels in order to facilitate the detection.

In the second example (Figure 7.G), the aim is to show, by means of a second spectral band (MSS 5, for example), the combined effect of the contrast and the mean reflectivity at the resolution limit. We already know that in this case the feature CA appears as a uniform field ($\ell_{CA} = \infty$ in MSS 5); in the other cases:

- $\ell_{CS} = 45$ m in MSS 5,
- $\ell_{AS} = 46{,}5$ m in MSS 5,
- $\ell_{AA} = 61$ m in MSS 5.

On the other hand, when ℓ is larger than these, re-sampling will not result in any supplementary information.

b - Limit of resolution in spectral fidelity

In most of the methods of data processing, in remote sensing, the experimenter must conduct a spectral support phase in the course of which a double unequivocal relationship must be created between

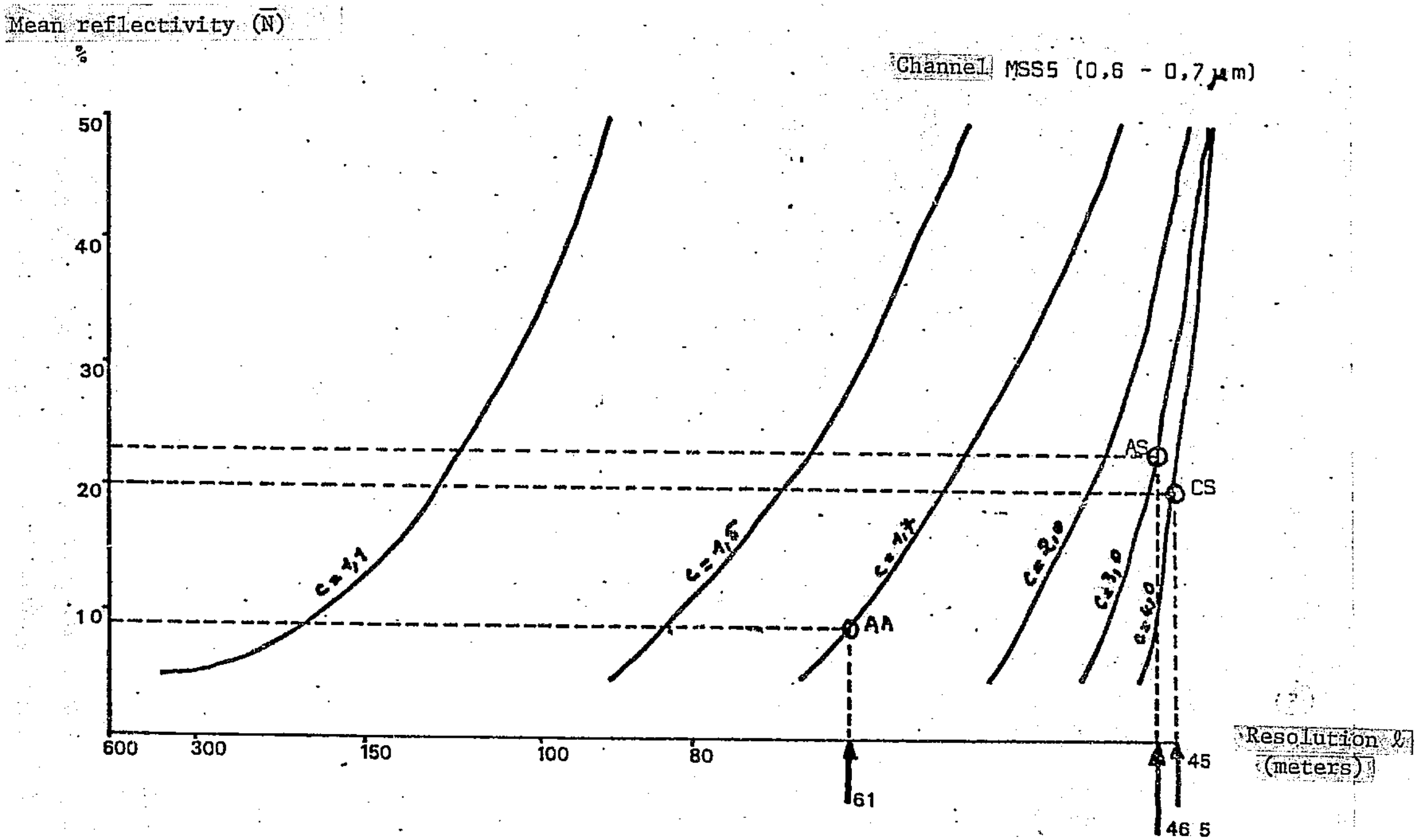


Figure 7.G. Graph giving the detection resolution ℓ as a function of the mean reflectivity ($\overline{N}$) and of the contrast (C) for spectral band MSS 5

/55

the type of object and the spectral signature which characterizes it. To the problem of the detection of objects, there is therefore joined that of the "purity" of the spectral signatures thus collected.

We again engage ourselves in the matter of the binary features described above in asking ourselves which circumstances will assure that the spectral signature of a cultivated plot from the MSS radiometer is most characteristic of this type of object. /56

The response to this problem is given by a curve called square wave response, giving the maximum amplitude of the signal as a function of the value L of the rectangular bands of the feature model adopted. This curve, independent of the wavelength of the observation, is presented in Figure 7.H. The absolute maximum amplitude $\overline{N}'$ observed in the output of the MSS radiometer is obtained by a value L determined by multiplication of the actual mean reflectivity $\overline{N}$ by a corrective term $A(L) \leqslant 1$:

$$\overline{N'} = A(L) \times \overline{N}$$

There will then exist a diminution of the spectral fidelity of the MSS radiometer as a function of the shape of the object observed. This phenomena is illustrated in Figure 7.I where, for an input signal corresponding to a succession of two types of objects marked by the respective reflectivity N'_1 and N'_2, the maximum amplitude of the radiometer measuring signal varies as a function of the shape of these objects.

According to the characteristics and the performance of the classification system used, the spectral support phase imposes a fidelity threshold below which the spectral signature cannot be considered pure. In general, one will select a threshold A = 80%, which sets the spectral fidelity resolution limit L at 100 m.

In conclusion, it is necessary to distinguish, at the level of the utilization of LANDSAT data, the resolution limits for detection

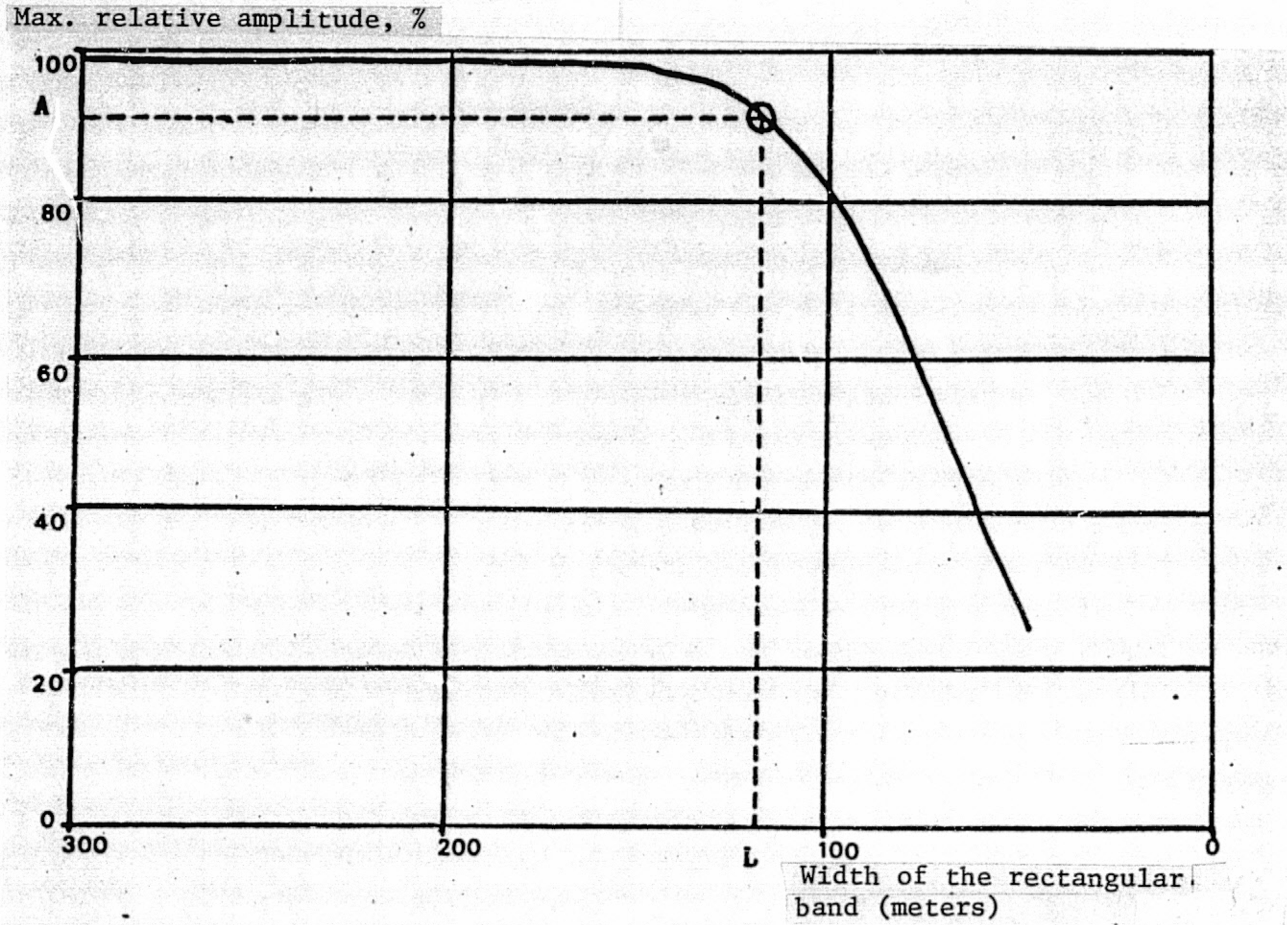


Figure 7.H. Square wave response of the MSS radiometer

and those for spectral fidelity. The first come into play in the definition of the geometry of objects and can give rise to the interpolation of the data in certain cases. The second impose a limit on this side of which one can come down without strongly changing the quality of the spectral information. The most unfavorable case is encountered when the detection resolution is worse than that of the spectral fidelity (ℓ < 100 m), as for example is the case in MSS 7 with thickets of shrubby vegetation on argilaceous-sandy soil. Finally it should be noted that the values presented in our paper correspond to a theoretical mode; they must be considered to be the upper limit of the performance that one can expect from LANDSAT.

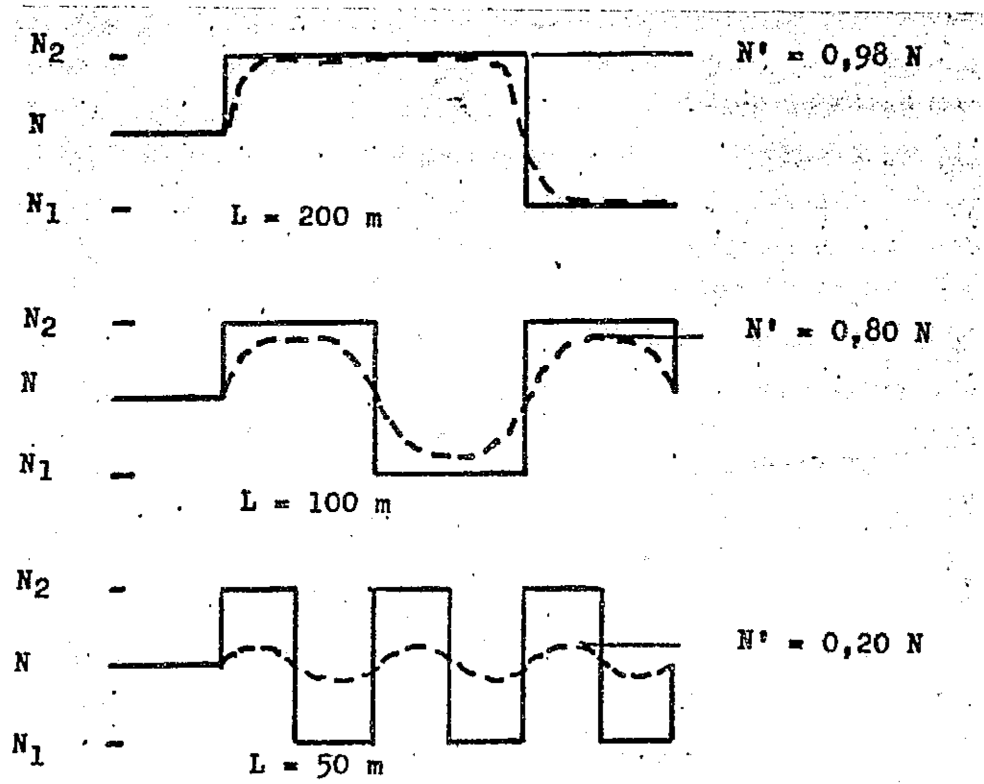


Figure 7.I. Diminution of the spectral fidelity of MSS as a function of the size of the objects as observed

The solid line is the input signal; the dotted line is the MSS response

7.2.2.3. The geographical features /58

a - The principal features

The principal features of the test area are the following:

- river waters,
- standing water in ponds and puddles,
- flooded areas,
- green vegetation,
- bare sand,
- urban quarters of traditional poto-poto habitations,
- urban quarters of modern habitations,
- cultivated areas on burnt-over terrain.

This general taxonomy of the area enables identification of the test area and guides the simplest choice of the classification.

b - The recognition and the location of features

The recognition and location of features must be the more precise seeing that one wishes to carry out the dichotomy of a group, for example, that of very green vegetation in which wooded areas and forests are distinguished, on the one hand, and meadow areas or bottom land cultivation, on the other.

In the successive steps of classification, each feature must be recognized with the maximum precision allowing the interpretations of the variations in spectral statistics.

This very precise taxonomy allows two types of support:

- an internal support beginning with the recognition of the spectral characteristics of the processed data; this permits decisions about the choice of classification;

- an external support enabling one to take account of other data than that which one is processing, notably the knowledge acquired in the investigations of ground truth concerning the possible or probable evolution of the features during the dichronic analysis, i.e.,

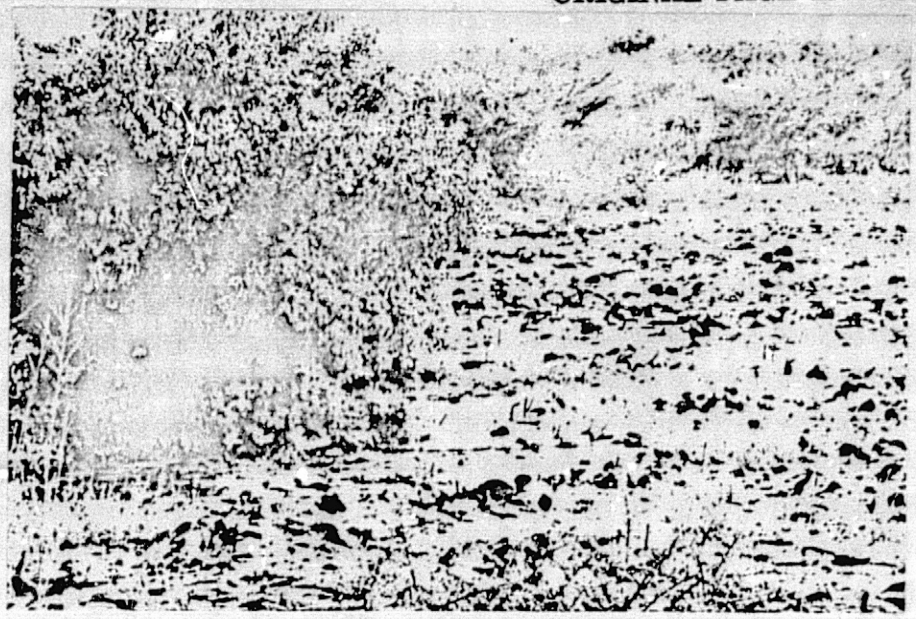
  • change from water or wet areas into dry,
  • the agricultural calendar, etc.

Geographic support allows both the precise determination of the limits of a feature studied and the forms of the seasonal evolution of this feature.

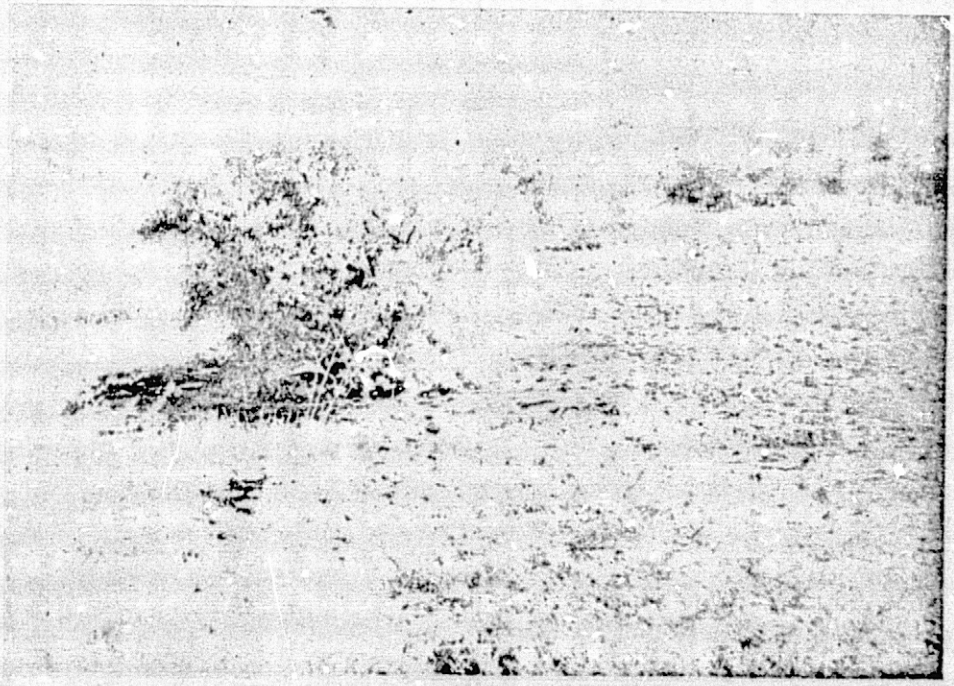
c - N'Djamena area /59

In this area one has determined the following geographic features:

- sands:
  - bare and dry,
  - dry with vegetation of low chlorophyll
  - damp,
  - wet;
- waters:
  - flowing rivers of many degrees of turbidity,
  - standing water of ponds, puddles, and flooded areas;
- water and vegetation complexes (Plates C, D, F):
  - ponds with bushy vegetation or with water lilies,
  - shrubby flooded areas;
- damp or wet soils with transient vegetation;
- wooded areas of high chlorophyll (Plate E);
- soils dominated by spiney vegetation:
  - black tropical argiles,
  - argiles with chalky concretions,
  - argile sands,
  - argile silts,
  - sandy argiles;
- sandy ridges of the bank or of the old hydrographic networks;
- cultivated areas (Plates D and E):
  - dry land cultivations on burned-over areas,
  - flood plain cultivation,
  - cultivation in rainy areas
  - bottomland cultivation
  - fruit tree cultivation;
- urban areas (Plates G and H):
  - areas of modern construction with strong reflectivity,
  - areas of modern habitations — villas and gardens,
  - landscaped urban areas of trees with high chlorophyll,
  - suburban areas of scattered habitations,
  - bare urban spaces of high reflectivity (stadium, racetrack, square ...).



1



2

Plate C. Koundoul Road, October 29, 1975

1 — panchromatic; 2 — infrared;
foreground — pond with water lillies;
middle distance — trees with high chlorophyll;
rear — copse of acacias

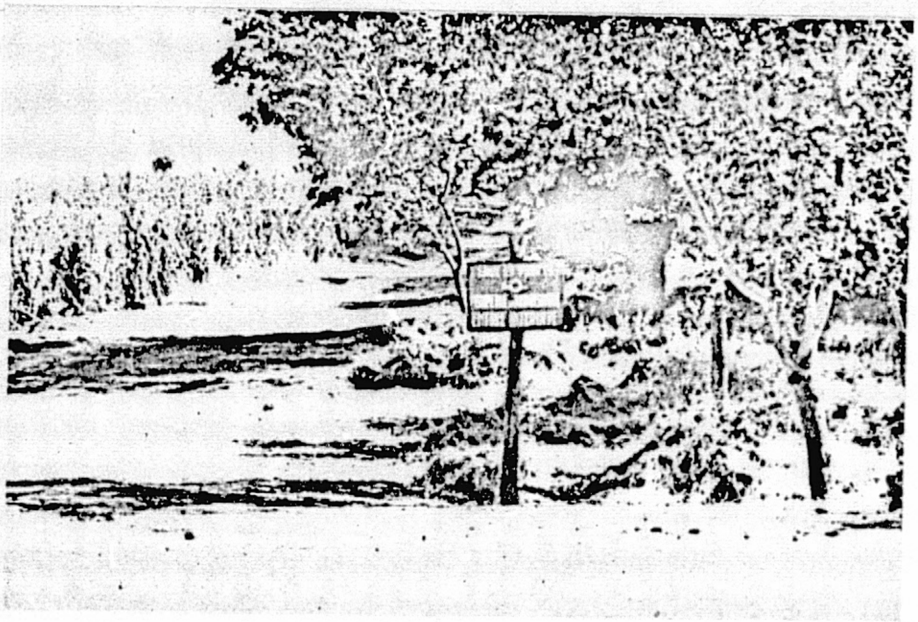
1

2

Plate D. Koundoul Road, October 29, 1975

1 — panchromatic; 2 — infrared; foreground — pond with spiney plants and water lillies; middle distance — field of manioc; rear — field of sorghum

/62



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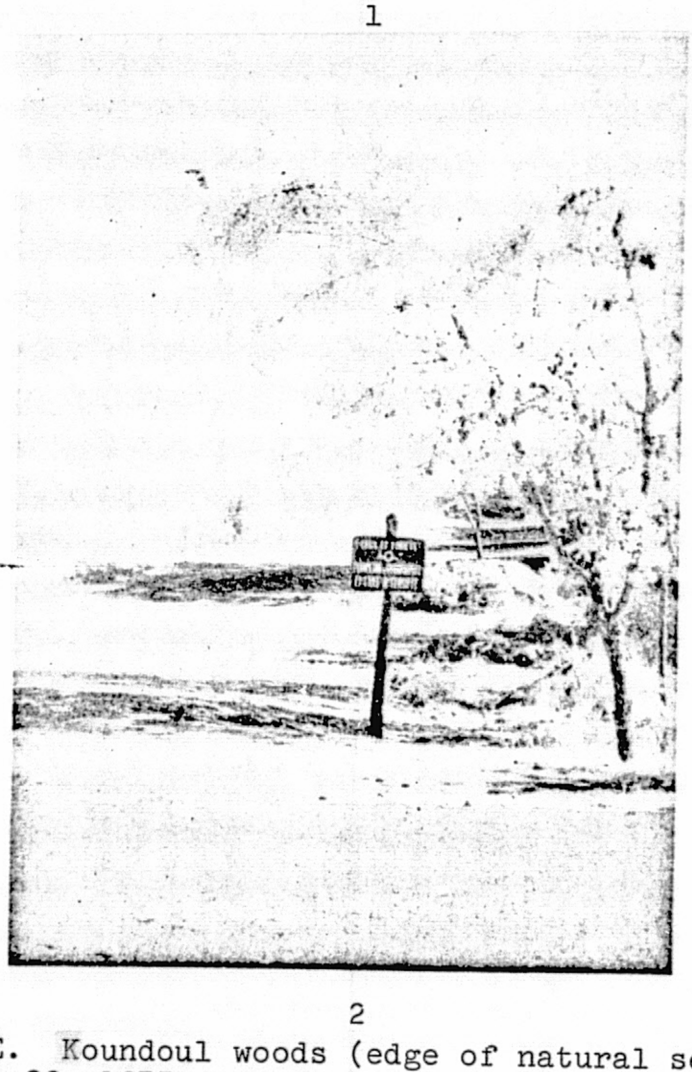
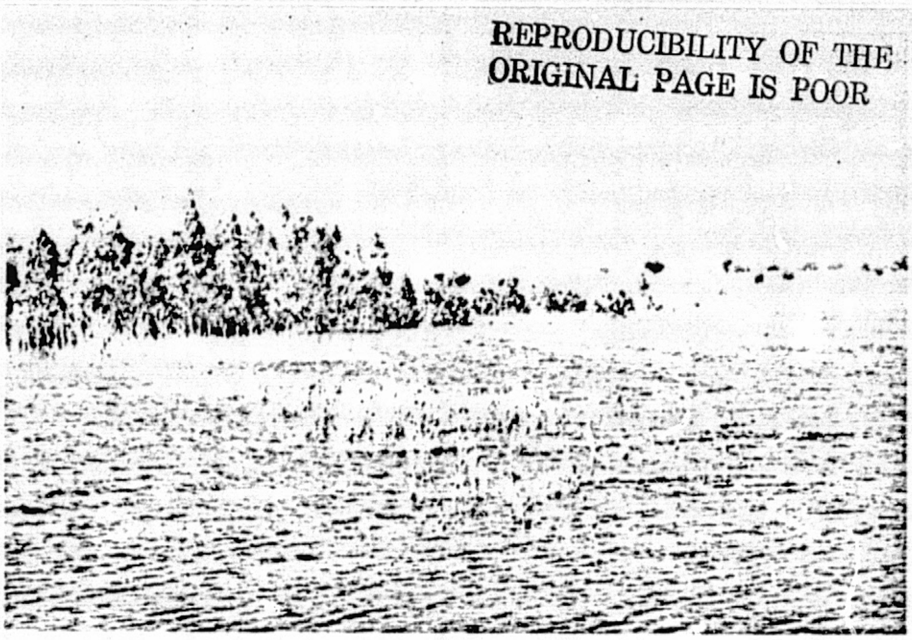


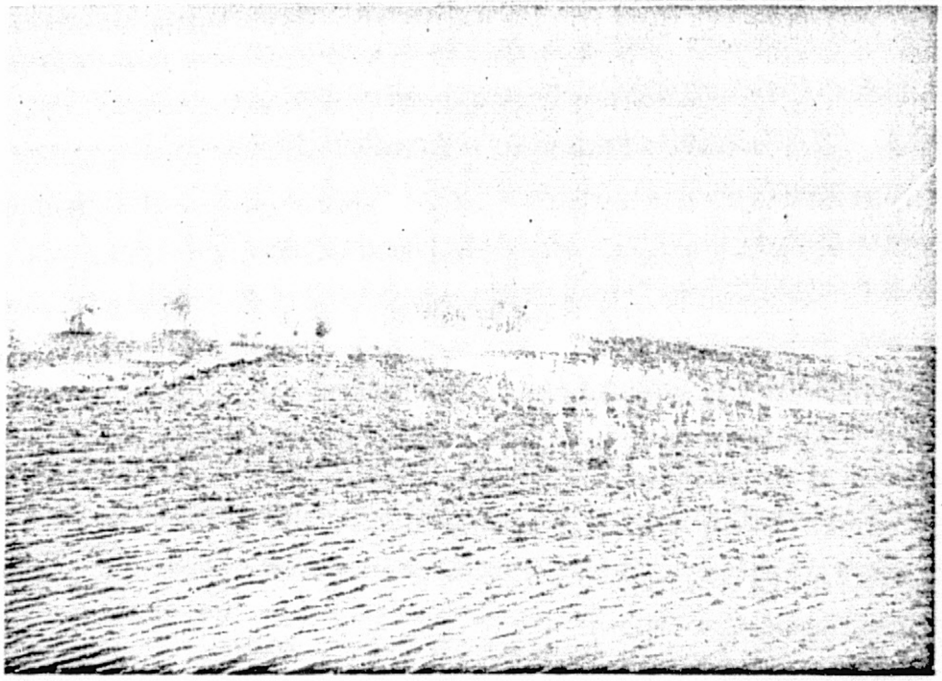
2

Plate E. Koundoul woods (edge of natural second growth) October 29, 1975

1 — panchromatic; 2 — infrared; foreground — blacktop road; middle distance — right, protected replanting; left, sorghum field



1

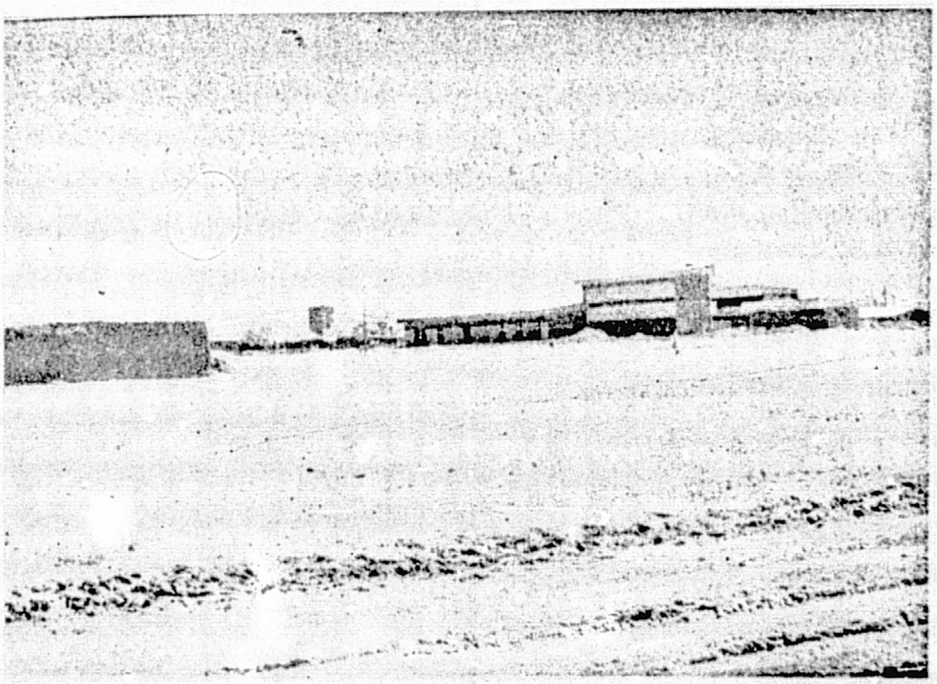


2

Plate F. Replanting of eucalyptus, Koundoul Road, October 29, 1975

1 — panchromatic; 2 - infrared; foreground — flooded area, stalks of sorghum projecting from the water; middle distance — replanting of eucalyptus in 1.2 m of water; rear — flooded area

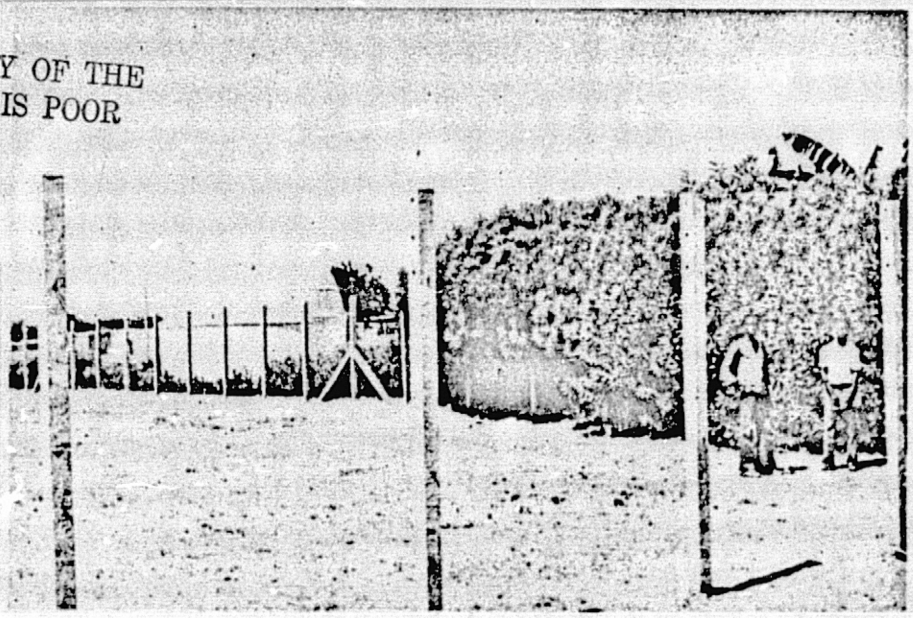
1



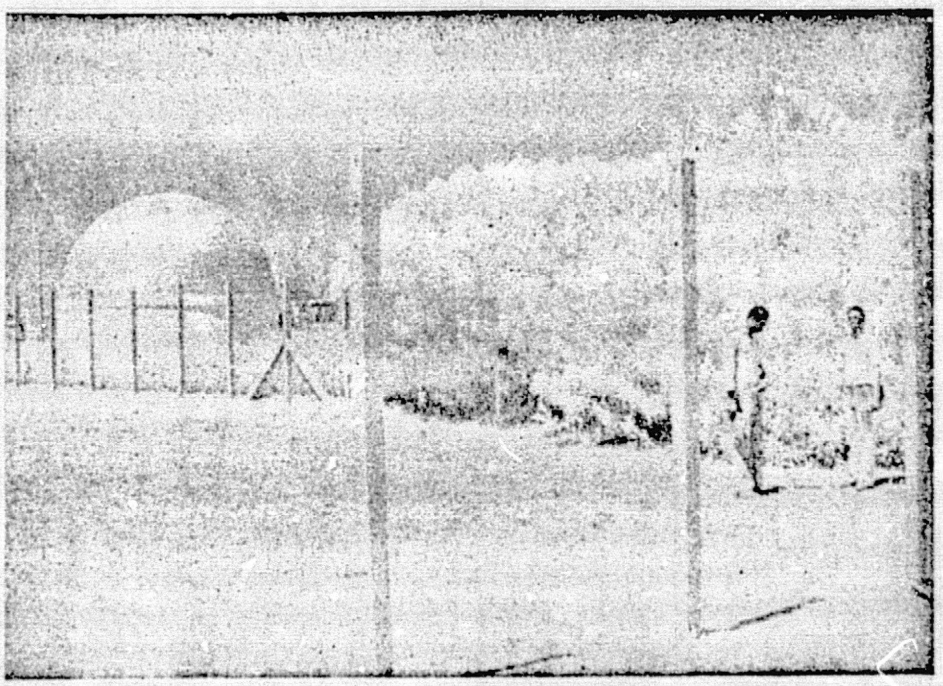
2

Plate G. N'Djamena, December 14, 1975, site of the industrial secondary school

1 — panchromatic; 2 — infrared; foreground — bare soil and dirt trail (argilaceous sand; background — the school, aluminum sheet roof, traditional poto-poto habitation



1



2

Plate H. N'Djamena, December 15, 1975

1 — panchromatic; 2 — infrared; foreground — bare argilaceous sand and concrete posts; middle distance — observatory dome and hedge of high chlorophyll

7.2.2.4. Objects identified in the taxonomy of the N'Djamena area

In carrying out a descending classification, it is indispensable to locate the significant objects for each type of feature.

In the N'Djamena area, the following objects have been located: /66

- old meanders and beds of the Chari going from damp to very wet with green vegetation (brush or cultivation),
- ridges of the bank present and past (sand berms of great reflectivity),
- present and past drainage networks,
- green areas, woods, and gardens at Milesi and Farcha,
- green urban zones of quarters and boulevards planted with trees,
- urban quarters according to the type of habitation and their network,
- urban spaces of specific reflectivity,
- agricultural type areas.

A more precise nomenclature for these objects classified by feature can be described as follows:

Urban features (Plates G, H, and Figure 7.J)

- urban quarters dominated by greenery: Djamb and N'Gato, Rond-Point, Etoile, Matembe where a habitat of villas with gardens and tree-lined avenues predominates;
- the Bololo, Djamb el Barr quarters of very closely packed network, with trees;
- the Avenue Mobutu, University, Eboue Secondary School district dominated by tree planting;
- the Gardole, Sabangali quarters where the Italedyl developments predominate (strongly reflective roofs and gardens with shrubbery);

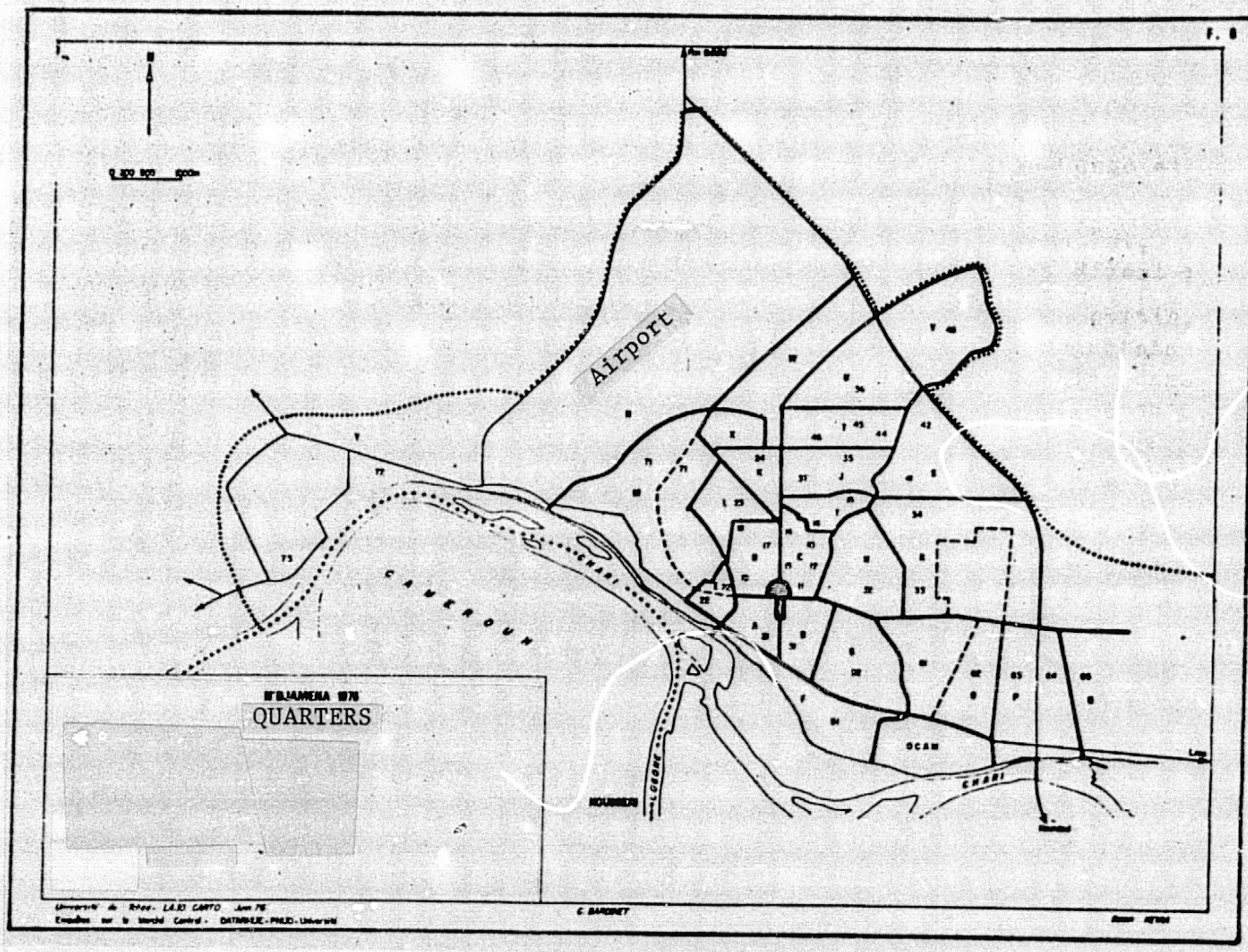


Figure 7.J. Map of N'Djamena at 1/100,000 with district toponymy, 1976

Legend: —— quarter boundaries; . — quarter names; --- — sub-quarter boundaries; ··· — limit of conurbation; +++ — international frontier; —— — principal roads; — — — limits of the banks; — rivers; — central market - mosque

A – Gardole
B – Ambassatna, Kabalaï
C – Blablim, Centre
D – Mardjâm Dafaq
E – Bololo Djamb el Bahr
F – Sabangali
G – Ardeb Djomâl
H – Ridina
I – Soldiers home
J – Hille Arab, Sarro, Hille Leclerc
K – Zouta Al Hamra
L – Kileb Mât
M – Djanb an N'Gato, Matambe, Etoile

N – Airport
O – Moursal, Paris Congo
P – Chagoua
Q – Dembe
R – Zongo, Grediya (radio stn.)
S – Am Riguebe, Hille Gazâz
T – Cholera Clinie, 40th St.
U – 30th St. (Gozator)
V – Diguel
W – Naga
X – Syrte
Y – Farcha, Milêzi
Z – Ocam

- the Cite O.C.A.M. district where there is a mixture of development, bottomlands, reforestration;
- gardeners' ponds;
- the I.Z.V.A.C. gardens and the Farcha cemetery;
- the airport area;
- the urban spaces of strong reflectivity, racetrack, St. Martin plain, the Gredyia antennas;
- the central market district with the great mosque and the House of Congress;
- the Chari bridge at Chagoua;
- the traditional residential districts around courtyards, arrange in a close network, in particular: Ambassatna, Kabalai, central Blablim, Mardjan Dafaq, Ardeb Djomal, Ridina, Bout al Hamra, Hille, and Sarro;
- the traditional residential districts with scattered dwellings, in particular: Naga, Adiquel, Am Riguebe, Gredyia, on the one hand, and, on the other hand, Sara Moursal, aris-Congo, and Chagoua west; /68
- the nearby urban districts Adiguel North, Chagoua East, Dembe, Goro Waga on the east and, on the west, Farcha and Milesi;
- Kousseri (formerly Fort Foureau) in Cameroon, partly along the Chari in the category of modern urban districts with tree-lined avenues and partly with traditional residences tightly packed in the middle and scattered out to the south.

Vegetation features with high chlorophyll:

- Milesi woods;
- the Kouseri woods and the Kalamaloue Reserve in Cameroon;
- the Koundoul woods;
- the bottomlands and orchards of Goro Waga, Gassi, and Mandjaffa;
- the Digangali bottomlands;
- modern irrigated farms at Koundoul, Malo in Chad, and at N'Douf in Cameroon.

Sandy features and ridges of banks:

- the Irounda flood area downstream from Milesi;
- the Chari flooded areas, in particular near the bridge at the confluence with the Lagone.

Features of the old meanders of the Chari at Dignagali and Riguil.

Lake and pond features, in particular at Dembe and Njair, to the north and east of N'Djamena, in the close-in urban zone and to the southwest of Kousseri and of Mont Ct. Lamy.

The objects which were located can be classed into three types:

- those where the reflectivity varies little over time,
- those where the reflectivity is complex and variable,
- those where the reflectivity did not vary during the observation period.

7.3. The FOR 3 map at 1/100,000: geographical taxonomy of the N'Djamena-Kousseri area /69

This map was created starting with a selection of data in the FOR 3 classification described in section 8.3.3. The basic data are those of LANDSAT 1, image E 1173 08513 of January 12, 1973.

The refinement of the controlled classifications allows finally the classifying of the basic numerical data as a function of their taxonomical significance. This classification can only be created on an index of reduced dimension — in this case, 40,000 pixels.

The question which arises here is that of the extension of the classification to all four strips of the image under study. This question cannot be resolved directly, and one cannot consider applying the classification created in the test area to the entire image.

7.3.1. <u>Identification through the classification of significant objects in the taxonomy</u>

Beginning with the controlled classification of the test zone, it is, on the other hand, possible to identify the spectral signature of certain key objects in the taxonomy.

One of the objectives is to measure, from the perspective of land management:

- the evolution of the cultivated areas,
- the extent of the burned-over areas connected with traditional agriculture,
- the spatial extent of beneficial vegetation in the rural and urban economies,
- diminution of the vegetation on account of the intensive exploitation carried out by stockmen, farmers, foresters, and urban developers.

In the four channels, the selection of the reflectivity level for these objects is possible starting with the spectral statistics of the various classification groups. This technique makes use of electronic filtering means which isolate, in the four channels of the image, the objects according to their specific signature in two or more channels. The limits of the coding can be considered to be an upper and a lower filter.

On the map which is annexed, there have thus been determined:

- <u>flowing waters</u> exclusive of all lakes and flooded areas which can be cultivated during subsidence,
- <u>burned-over areas</u> which are signs of man's actions in the countryside — actions by herdsmen and farmers, /70
- <u>vegetation areas</u> which one observes according to the more or less great intensity of the chlorophyll effect. These allow the location of dense forestation, diminished forestation and, depending on the progress of the vegetative cycle, cultivated

zones and pasturage,

- sandy areas without vegetation which mark the uncultivated and arid spaces in the countryside.

One of the characteristics of this cartography lies in the selection of the patches or pixels as a function of a thematic analysis. All the pixels not concerned with this analysis are, in the map presented in the annex, represented by a white space.

This is to say that, at the maximum, it is possible then to create a thematic map considered useful from the point of view of land management so long as the spatial extent of the phenomena observed and measured is characterized by the level of specific reflectivity.

7.3.2. Cartography using the satellite image data bank

Finally, one here approaches the possibility of creating a data bank beginning with the indices constituting the recordings made with artificial Earth satellites.

This data bank is only possible if the analysis through controlled classification, in the case of a well-located geographical region, has allowed us to establish a good relationship between spectral statistics and geographic taxonomy.

But, when this objective has been reached, one can consider that for the area studied a geographical data bank is on the way to being constituted. This ought to allow one to consider the later use of data outside that of the digital image which results from the collection of qualitative and quantitative information localized to the ground.

The data bank used for land management appears now to allow a thematic cartography resulting from the combined analysis of digital data from the satellites and of data collected on the ground by

direct investigation or by other methods as for example photography in black and white, color, infrared, and false color.

CHAPTER 8 - CHRONOLOGY OF COASSISTANCE PROCESSING

The descending classification method was used for establishing legends of FOR 1, FOR 2, and FOR 3, and then for FOR 1.2, using spectral coassistance and post assistance taxonomy. We will summarize the processing sequence for each map by using several selected examples. This allows us to explain the problems encountered in the identification of the main feature objects as a function of the spectral statistics on the one hand, and of the binary image cartography at the scale of 1:100,000 and 1:80,000. /71

8.1 FOR 1 Processing Sequence

The classification in steps, using successive cutting off of groups (spectral coassistance) as a function of their taxonomic importance, is based on the analysis of transformed canal boundaries and their interpretation on the binary image.

The following two tables summarize the classifcation steps using five groups, and then other sub-groups.

8.1.1 Classifications of FOR 1

Groups	SubGroups	Transformed Canals and Reflection Levels	Features
1		A8 B8 C9 D8 66 73 71 31	Sandy
2	21	A1 B1 C1 D1 40 35 39 18	Water and Puddle Vegetation
	22	C2 D2 A5 B4 43 18 47 45	Puddle Water
	23	C4 D4 49 24	Dense Vegetation and Forests
	24	B2 C3 D3 38 45 21	Bush Vegetation
3		C1 D1 35 11	Deep River Water
4	41	C4 D4 A4 B4 66 30 61 67	Sandy Argiles

	42	C3 D3 64 29	Uncovered and Dry Argiles, suburban /72
4	43	C1 D1 A2 B2 60 27 58 62	Traditional central urban area
	44	A1 B1 C2 D2 50 60 61 28	Dry Argiles, dry vegetation
5	51	A1 B1 C1 D1 45 44 50 24	Green village, modern urban area
	52	C1 D1 B2 49 22 48	Black argiles, cultures, vegetation
	53	A2 B3 C2 D1 49 49 53 25	Sandy argiles, humid and cultivated
	54	A6 B6 C4 57 59 57	traditional urban area
	55	A4 B4 C3 D4 51 53 55 25	sandy argile humid area
	56	A5 B5 C5 D5 53 55 57 26	sandy argiles

It can be seen that the coding boundaries are adapted for the classification into subgroups of groups 2, 4, and 5, so that in each group the transformed channels will have a taxonomic importance for the binary image.

8.1.2 Legend for the FOR 1 Map

The legend for the printed FOR 1 map which is given in the appendix gives the main features and the dominating objects for them, with consideration of the spectral statistics of each classification group. This legend is described in the following table.

Table 8.A Legend of Map FOR-1 /73

Color	Class Number	Dominant Objects	Features	Spectral Signatures 4	5	6	7
Blue	3	Deep rivers, high waters of the Chari and Logone, turbulent waterways.	rivers	50	50	35	11

	22	shallow puddle	puddle	47	45	43	19
	21	puddle water, vegetation of puddles, dried-up river tributaries	puddle water, vegetation	40	35	39	18
Green	23	Milesi and Kousseri forests, high chlorophyll vegetation	high chlorophill vegetation	43	39	49	24
	24	high chlorophyll vegetation, water marsh areas	chlorophyll vegetation	42	38	45	21
	52	berber soil, cultivation, vegetation	berber	48	48	49	22
	51	modern residential urban center, vegetation areas	green village	45	44	50	24
	53	humid argile soils, moderate chlorophyll	sandy argiles and vegetation	49	49	53	25
Red	43	inhabited close plot regions	traditional urban area	58	62	60	27
	54	dense plot inhabited areas	traditional urban area	57	59	57	26
Chestnut color	42	suburban, bare ground	bare sandy argiles	60	65	64	29
	44	high reflection on humid ground	sandy argiles	57	60	61	28
	56	river terraces	sandy argiles	53	55	57	26
	55	terraces and creeks	sandy argiles	51	53	55	25
Yellow	1	sandy riverbanks, creek boundaries	sandy	66	73	71	31
	41	zones projecting from the nagas and river edges	sandy argiles, nagas	61	67	66	30

8.2 FOR 2 Processing Sequence.

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The classification in steps, using successive cutting off of groups (spectral coassistance) as a function of their taxonomic importance, is based on the analysis of transformed canal boundaries and their interpretation on the binary image.

With respect to FOR-1, which occurs at the end of the rainy season in November, 1972, the image treated by FOR-2 observes the area in the middle of the dry season in February, 1973.

By comparing the two classifications, one can very clearly see a reduction in the rivers and the change in the flooded and humid areas and the chlorophyll areas into dry areas.

8.2.1 Automatic Classification by isopopulation levels for each channel.

In this step of the processing of the data, on the binary image we select the level intensities corresponding to a large number of features. The study of the intensity levels allows a first identification of the features.

The first result of automatic classification into three boundaries which separates classes of equal population in Channel 4 is given by the image shown below (Figure 8b). One obtains the selection of the water and the vegetation associated with the water.

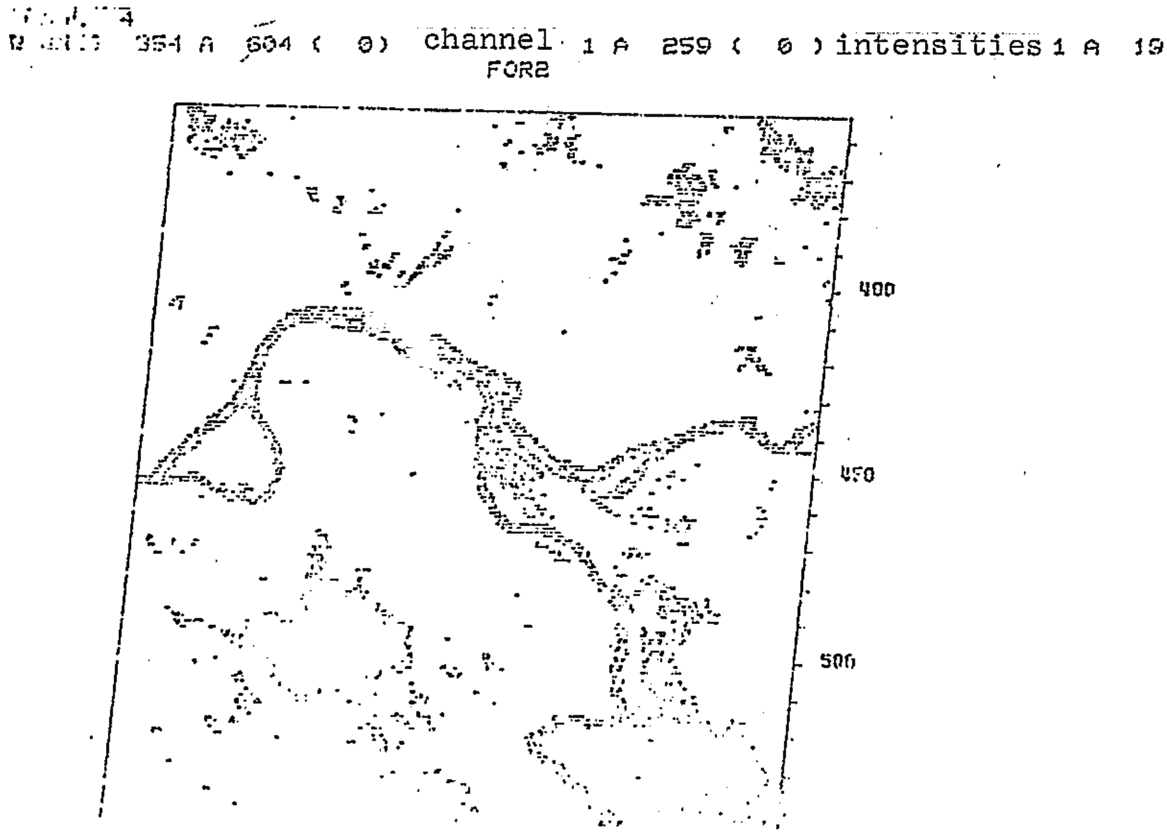

Figure 8.B. The FOR-2 ima e of Channel 4, rivers, and puddles.

In the channel 4 (MSS 7), reflection leve from 1 to 19 are asso- /75
ciated with the following objects within the same feature:

- rivers
- ponds and puddles
- flooded areas
- airport runways
- very humid and high chlorophyll zones.

The average luminescence of objects on this feature varies between 0.73 to 13.87 $W \cdot m^{-2}$ sr^{-1}. It can be seen that the airport runway has a low luminescence level.

We studied each intensity level before proceeding with the first classification. We observed trees near the transformed canals, and the resemblance between the isodensity levels of the four channels.

8.2.2 <u>First Classification of FOR 2 into Seven Groups</u>

8.2.2.1 Aggregation Control Parameters

Groups	Transformed channels and reflection levels	Objects	Features
1	C1 D1 19 5	Chari and Logone rivers	rivers
2	B10 A9 C9 D10 65 81 79 36	sandy banks, sandy river edges	bare and dry sand
3	B1 C3 D3 A2 40 39 18 40	Milesi and Kousseri wood	vegetation
4	C8 D9 66 31	bare urban areas, grediya	sandy argiles
5	B9 A7 63 54	Hwy 40, diguel, Sabangali, Kousseri, village, Chagoua	suburban and urban areas, sandy argiles
6	D8 B7 26 56	dense plot urban area	dry sandy argiles
7	C4 49	dense plot urban area and central urban area	dry sandy argiles

8.2.2.2 Coding Boundaries by Reflection Levels /76

Channel	Boundaries 1	2	3	4	5	6	7	8	9	10	11	Number of Boundaries
MSS 4	31	37	41	43	46	48	52	56	60	113		10
MSS 5	25	37	42	46	49	52	55	60	63	67	127	11
MSS 6	1	22	34	42	49	54	58	63	72	127		10
MSS 7	1	7	15	19	21	23	25	27	29	33	63	11

The binary image of the group 2 shown below is an example of the first FOR-2 classification.

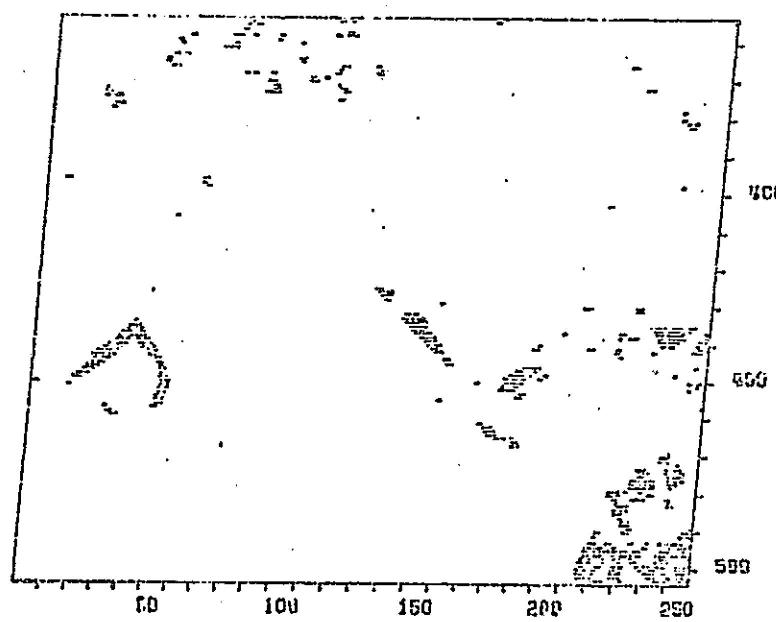

Figure 8.C. Binary image of Group 2, identification of sandy areas is clear on the image.

LIGNES 354 A 504 (0) Columns 1 A 259 (0) Intensities 0 A 255
FOR2
Studied Class. 2

8.2.3 The second FOR classification into fifteen classes.

In the second step, Grups 3, 6, and 7 are subdivided as a function of the selection based on the proximity scale of reflection levels which characterize the main objects of taxonomy.

8.2.3.1 Analysis of the Binary Image of Subdivided Group 3

a- Aggregation control parameters

sub groups	transformed canals and reflection levels	Objects	Features
31	A1 B1 C4 D5 38 36 44 22	Milesi forest, Kousseri forest, I.Z.V.A.C. gardens, green village, old meanders	high chlorophyll vegetation
32	A4 B4 C3 D3 42 43 41 19	cultivated areas, bottom land cultivation, overgrown bottom land regions	chlorophyll vegetation

33	C1 D1 30 11	riverbank water, puddle wet zones	water and humidity
34	C2 D2 A3 B3 38 17 40 39	center of puddles	puddle water

On the following page, two illustrations of the binary image of group 3 are given.

b- <u>Coding boundaries for group 3</u>

Channels	Boundaries						Number of boundaries
	1	2	3	4	5	6	
MSS 4	31	38	40	41	53		5
MSS 5	25	36	39	42	53		5
MSS 6	5	36	39	42	59		5
MSS 7	7	15	17	19	22	63	6

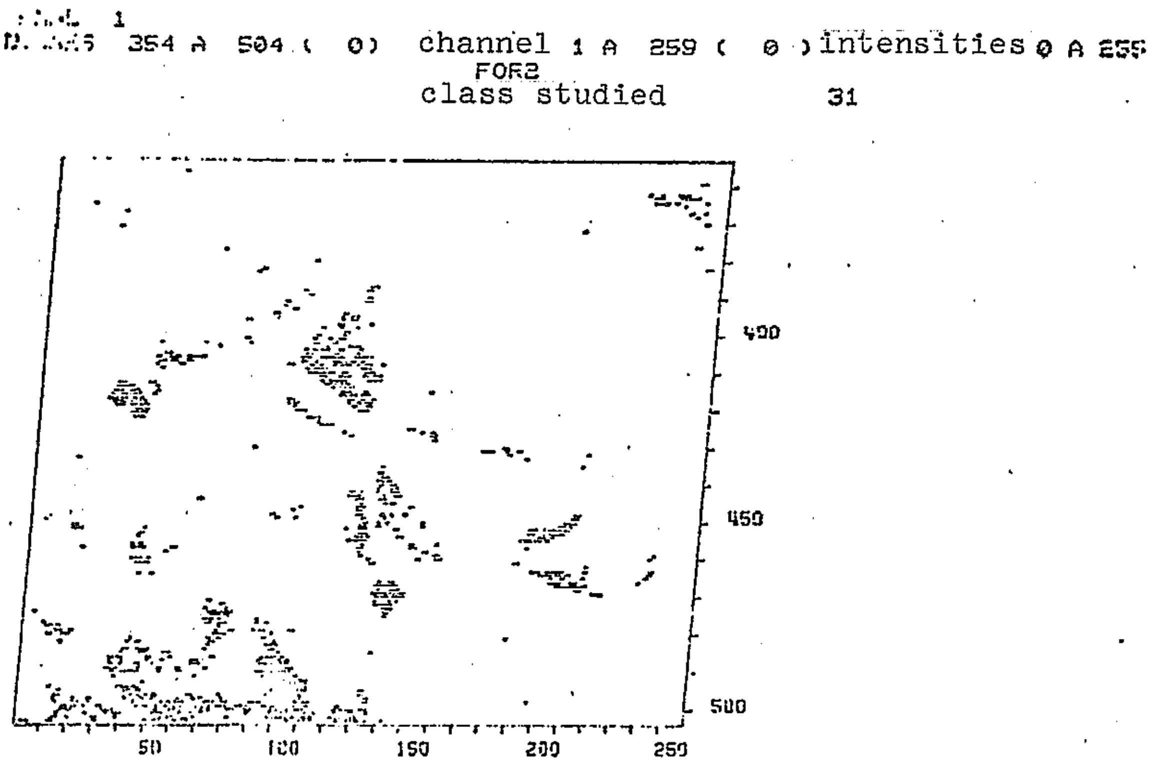

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Figure 8.D. Group 3 binary image: Class 31. Identification of the high chlorophyll vegetation areas is very clear.

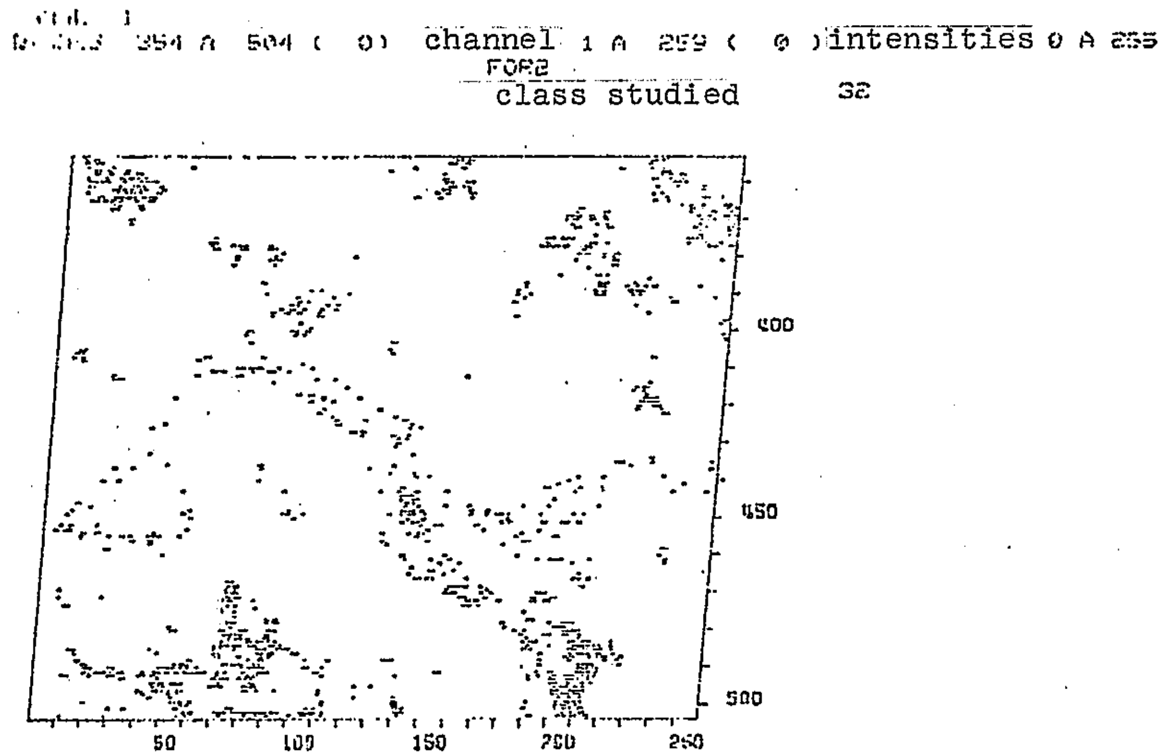

Figure 8.E. Binary image of group 3, class 32. Identification of average chlorophyll areas in relation to the puddles and the bottom land areas.

8.2.3.2 Analysis of the Binary Image of Subdivided Group 6.

a- Aggregation control parameters

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Subgroups	Transformed channels and reflection levels	Objects	Features
61	C4 D4 58 27	Levels higher than terraces, river-banks	dried-up sandy argiles
62	A1 B1 46 53	urban islands with high reflectivity, modern construction, river terraces	dried sandy argiles
63	C1 D2 54 25	traditional inhabited areas, sandy argile dry areas	traditional inhabited areas.

b- Coding boundaries for Group 6

Channels	Boundaries 1	2	3	4	5	Number of Boundaries
MSS 4	40	46	49	52	100	5
MSS 5	25	52	56	60	127	5
MSS 6	2	53	55	57	106	5
MSS 7	1	24	26	28	34	5

The study of the group 6 subgroups shows the overall drying pattern of the soil and of the vegetation of the terraces and the urban zone. The chlorophyll effect seems to disappear. It is possible to distinguish group families of soils, and the urban morphology, depending on the construction types.

[illegible] 1
[illegible] 354 A 504 (0) channel 1 A 259 (0) intensities 0 A 255
FOR2
class studied 62

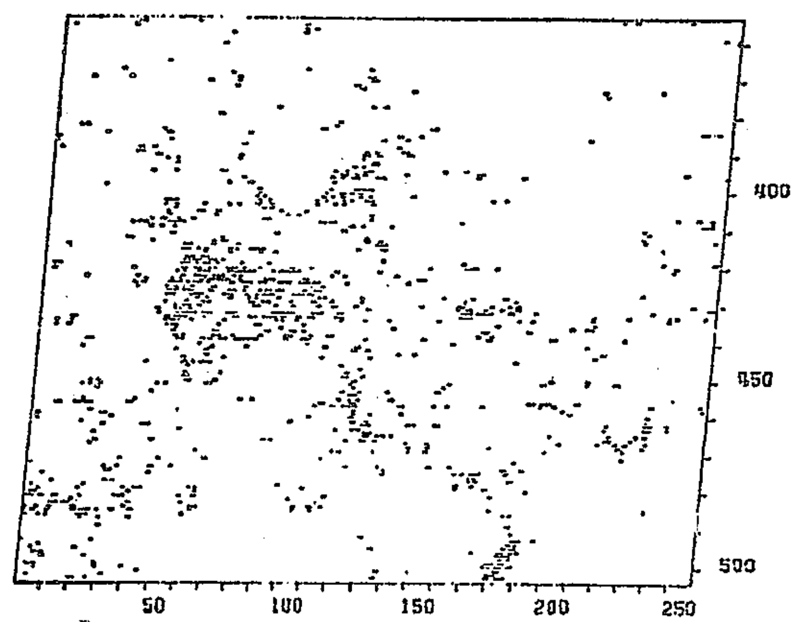

Figure 8.F. Binary Image of Group 6: Class 62. Identification of several urban islands with high reflection.

8.2.3.3 Analysis of the binary image of subdivided group 7. /80

As examples of this analysis, we give Figures 8H and 8G:

a- <u>Aggregation control parameters</u>

Subgroups	Transformed Channels and Reflection Levels	Objects	Features
71	A4 B4 47 51	Traditional high density areas, sandy argile ground	Traditional Urban Areas
72	C4 D4 53 26	Urban areas with high reflection, modern construction, dried sandy argiles	Modern urban area, bare argiles

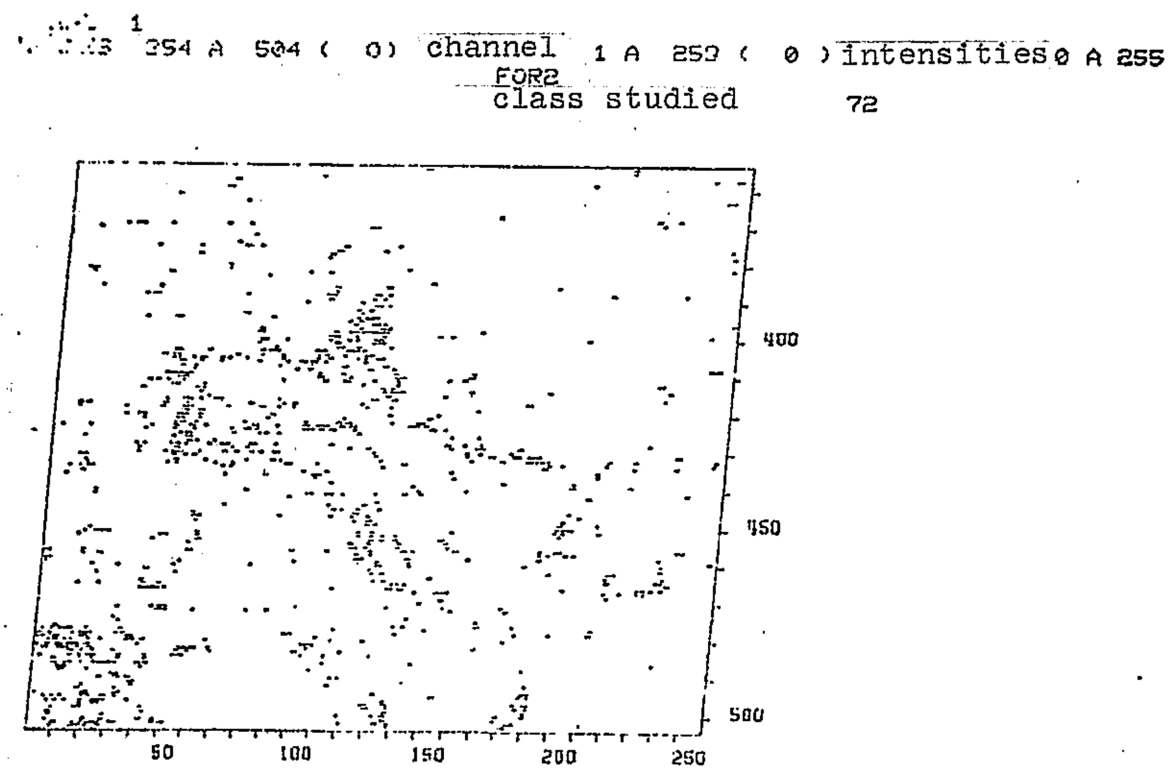

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Figure 8.G.: FOR-2 binary image: urban areas with high reflection and dried argile soil.

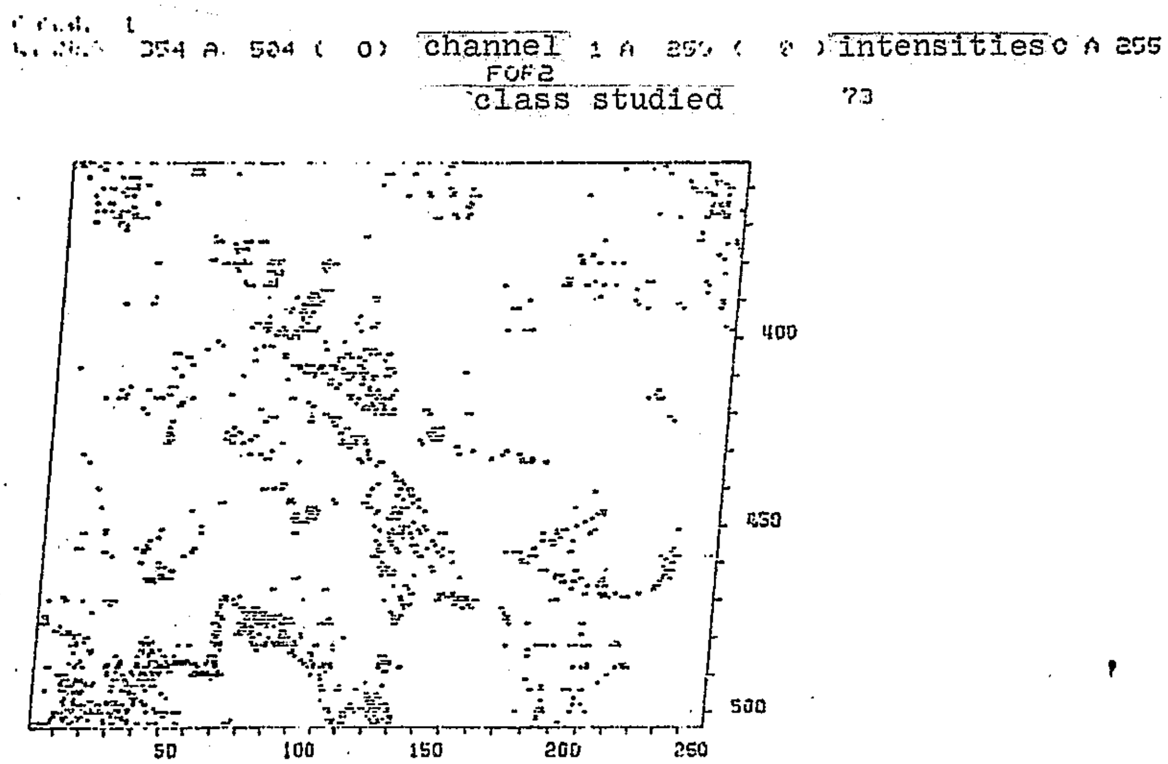

Figure 8.H. Binary Image of FOR-2: Drying out of bottom land, river beds, and green urban areas.

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Subgroups	Transformed Channels and Reflection Levels		Objects	Features
73	A1 41	B1 44	Dried-out puddle areas, urban areas, during drying out	Dried bottom lands, urban areas
74	C1 47	D1 22	Dried puddle edges	dried bottom lands

b- Coding boundaries of Group 7

Channels	Boundaries					Number of Boundaries
	1	2	3	4	5	
MSS 4	31	42	45	48	113	5
MSS 5	25	44	48	53	127	5
MSS 6	1	45	49	53	127	5
MSS 7	1	21	23	25	63	5

A study of the sub-groups of group 7 shows the drying out of humid argile regions including the urban areas. The urban areas differ according to modern or traditional high-density construction methods.

8.2.4 FOR-2 Classifications

7 groups	15 groups
1	1
2	2
3	31 32 33 34
4	4
5	5
6	61 62 63
7	71 72 73 74

8.2.5 Legend for the FOR-2 Map /83

The final FOR-2 map legend shown in the appendix can be used to locate the main features and the dominating objects with consideration of the spectral statistics of each classification group.

Color	Class Number	Dominating Objects	Features	Spectral Signature			
Blue	1	Chari and Logone rivers	rivers	40	33	19	5
	33	river edge waters, wet puddle areas	water and humidity	41	39	30	11

	34	center of puddles	puddle	40	39	38	17
Green	31	Milesi and Kousseri forests, IZVAC gardens, green village, old meanders	high chlorophyll vegetation.	38	36	44	22
	32	cultivation, bottom land overgrown areas	chlorophyll vegetation	42	43	41	19
Red	72	high reflection urban areas, modern construction, dried argile soil	modern urban area, bare argiles	45	49	53	26
	71	Traditional plot areas, sandy argile soils	traditional urban areas	47	51	50	23
	63	traditional residence urban areas, dried sandy argile areas	traditional urban areas, sandy argile areas	50	56	54	25
Chestnut color	5	urban and suburban traditional area, Hwy 40, Diguel, Sabangali, Kousseri-village Chagoua, ...	Traditional urban area, sandy argile area	54	63	61	28
	61	levels of terraces, river edges	dried sandy argiles	50	58	58	27
	62	urban islands with high reflection, terraced rivers	dried sandy argiles	46	53	56	27
	73	dried edges of puddles, urban zones undergoing drying	dried bottom lands, urban areas	42	44	47	23
	74	dried edges of puddles	dried bottom lands	45	48	47	22
Yellow	2	bare and dry sandy banks revealed by settling	sandbanks, sandy river edges	65	81	79	36
	4	sandy river edges and halomorphic soils	urban bare areas nagas	58	68	66	31

8.3 FOR-3 PROCESSING SEQUENCE /84

The classification in steps, using successive cutting off of groups (spectral coassistance) as a function of their taxonomic importance, is based on the analysis of transformed canal boundaries and their interpretation on the binary image.

The following tables illustrate this for FOR-3

8.3.1 First Classification of FOR-3 into Five Groups

8.3.1.1 Control Parameters of Aggregation Before Co-assistance. /85

Groups	Transformed Canals and Reflection Levels	Taxonomy Post-Assistance
1	C10 D9 A9 B9 62 28 53 64	sand
2	C1 D1 18 4	rivers
3	B2 A2 D3 34 36 16	vegetation, puddle waters
4	D8 A7 B7 24 47 54	sandy argiles
5	B3 A6 C5 46 42 45	urban, argiles

8.3.1.2 Separation coding boundaries

Channel	Boundaries 1	2	3	4	5	6	7	8	9	10	11	Number of Boundaries
MSS 4	6	33	36	38	40	42	45	48	52	82		10
MSS 5	22	31	36	42	45	48	51	57	62	104		10
MSS 6	14	21	30	37	40	45	48	51	54	57	108	11
MSS 7	2	6	12	15	18	20	22	24	26	63		10

8.3.1.3 Division of this Classification: Example of Group 3

In this first step, the groups 3, 4, and 5 are divided up, based on the selection of transformed channels as a function of their feature significance.

Therefore, group 3 is subdivided into five subgroups, 31 to 35, in which the selection of channels B1 and B2 and A2 characterizes in particular the subgroups 31, 32, and 33, where the high-chlorophyll vegetation dominates. The selection of channel D3 characterizes subgroups 34 and 35, where stagnant water of puddles dominates.

The following tables illustrate this classification of Group 3. /86

Sub Groups	Transformed Channels and Reflection Levels	Taxonomy Post-Assistance
31	A1 B1 32 29	highly-wooded chlorophyll vegetation, humid ground
32	C6 D6 42 21	High chlorophyll vegetation, woods, and shrubs
33	D4 15	Puddle vegetation in humid areas
34	C1 D1 27 10	Pixels of transition between water and riverbanks
35	A6 B6 C5 38 38 36	Low Chlorophyll humid zones, bottom lands.

The coding boundaries were modified, as given in the following table:

Channels	Boundaries 1	2	3	4	5	6	7	Numbers of Boundaries
MSS 4	28	33	34	35	36	38	46	7
MSS 5	22	30	32	33	35	37	49	7
MSS 6	19	29	32	33	35	38	49	7
MSS 7	5	12	14	15	17	19	26	7

8.3.1.4 First FOR 3 classification into 16 classes

The groups 4 and 5 are subdivided using the descending method. Finally, one obtains a first classification into 16 classes (five groups), which is summarized in the table on the following page. This first classification will be completely discussed in the following.

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Groups		Transformed Channels	Taxonomy
1		C10, D9, A9, B9	Bare sand, sandy argiles
2		C1, D1	Rivers
3	31	A1, B1	Forests, humid soil
	32	C6, D6	Forests, shrub carpet
	33	D4	Humid area and puddle shrub vegetation
	34	C1, D1	Transition pixels
	35	A6, B6, C5	Humid low chlorophyll bottom land areas, puddle waters.
4	41	A4, B5	Naga soil
	42	D4	Naga soil
	43	C3, B4, B3	Sandy Argiles and urban areas with high density
	44	C1	Sandy argiles and urban high density area
5	51	A1, B1	Modern urban areas and vegetation drying out
	52	C1, D1	modern urban areas and vegetation drying out
	53	A2, B2	very high density urban plot area
	54	B6, C5, D5, A5	low terraces
	55	A4, C2	high reflection urban area

8.3.2 Second classification of FOR-3 into nine groups.

Based on successive classification into five groups discussed above, a second classification is then carried out which leads to the final legend for Map FOR-3.

This second classification is a result of the first one with the following intermediate step:

First classification		Second classification			
Groups and Subgroups		Groups and Subgroups			Features
1		1	1	1	sand
2		2	2	2	river
3	31 32 33	3	31 32 33 34	31 32 33 34	vegetation
	34 35	4	4	4	puddle waters
4	41 42	5	5	5	sandy argiles, nagas
	43 44	6	6	6	sandy argiles
5	51 52	7	7	7	humid argiles
	53 54	8	81 82 83	81 82 83	argile silts to sandy ar-giles
	55	9	91 92 93 94	91 92	urban areas

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8.3.2.1 The 9 Groups of FOR-3

The separation coding boundaries and the control parameters for aggregation are described by the following two tables:

Channel	Boundaries											Number of boundaries
	1	2	3	4	5	6	7	8	9	10	11	
MSS 4	6	33	36	38	40	42	45	48	52	82		10
MSS 5	22	31	36	42	45	48	51	57	62	104		10
MSS 6	14	21	30	37	40	45	48	51	54	57	108	11
MSS 7	2	6	12	15	18	20	22	24	26	63		10

Class	Transformed Channels and Reflection Levels	Objects	Features
1	C10 D9 A9 B9 62 28 54 65	bars and river edges	sand
2	C1 D1 17 4	rivers	water
3	B1 B2 A2 34 36	forests, bottom land vegetation, green villages	vegetation
4	D3 13	puddles, dry river beds	water
5	B8 D8 58 26	nagas	sandy argiles
6	A7 B7 46 54	African urban area with low density plots	sandy argiles
7	A3 B3 38 39	green humid berber areas, partially urban (no large trees)	humid argiles
8	A6 44	river edges and terraces, low density urban areas	argile silts, sandy argiles
9	C5 44	modern urban central area, traditional central urban area with high density	urban area

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Aggregation control parameters.

The analysis of the binary image of the 9 groups allows one to introduce a subdivision of Groups 3, 8, and 9. Identificationof the dominating objects of the features is done from the intermediate outputs of the binary image during the spectral coassistance step.

The tendencies of the spectral statistics of the groups confirm the identification of the features.

FOR 3	Channels MSS 4	MSS 5	MSS 6	MSS 7
GR 1	53,62 4,02	64,57 5,37	62,14 4,94	28,00 2,24
GR 2	38,69 1,13	31,34 1,70	17,44 1,75	4,26 0,99
GR 3	35,94 2,82	33,91 3,68	35,28 5,43	16,50 4,25
GR 4	34,23 1,72	31,98 2,28	30,05 2,46	13,40 1,63
GR 5	49,15 2,52	57,92 2,14	55,55 1,69	25,55 1,10
GR 6	46,56 1,80	53,74 2,06	52,00 1,76	24,06 1,11
GR77	38,29 1,87	39,09 3,02	39,29 2,37	18,36 1,55
GR 8	43,66 1,31	48,79 1,81	48,19 1,54	22,38 1,27
GR 9	40,73 1,87	43,73 2,95	44,22 2,00	20,57 1,50

Spectral Statistics of Groups

8.3.2.2 Group 3 Subdivision into 4 subgroups

Channels	Boundaries 1	2	3	4	5	Number of Boundaries
MSS 4	28	33	35	37	48	5
MSS 5	22	31	34	36	51	5
MSS 6	30	35	40	108		4
MSS 7	2	13	17	20	63	5

Groups	Transformed Channels and Reflection Levels	Objects	Features
31	C3 D4 A1 B1 41 21 33 30	Milesi and Kousseri forests, IZVAC, central green modern urban area, Chari dried tributarites, green zones of cultivated puddles	vegetation forests, dense urban areas.
32	C2 D3 A2 B2 37 18 34 32	vegetation on argiles of bottom lands and puddles.	High chlorophyll vegetation.
33	D1 A4 B4 11 40 38	small islands, uncovered, shrub vegetation on sand-silt background,	vegetation of bottom lands
34	C1 D2 A3 B3 33 16 36 34	shrubbery on airports, shrubbery on bottom lands, acacia supal	bottom land vegetation.

Separation coding boundaries.

The selection of the transformed channel boundaries is done as a function of the feature significance.

Parameters for controlling aggregation.

Groups	Channels			
	MSS 4	MSS 5	MSS 6	MSS 7
31	33,18 1,75	29,99 2,64	40,24 4,94	20,65 2,98
32	34,18 1,84	32,27 2,90	37,09 1,63	18,53 1,21
33	39,98 1,75	38,07 3,57	29,73 4,73	10,90 2,90
34	36,14 1,61	34,51 2,08	33,62 2,28	15,68 1,68

Spectral statistics of groups

The tendencies of the spectral statistics of the subgroups confirm the feature identification.

8.3.2.3 Group 8: Subdivision into three subgroups

Channels	Boundaries					Number of Boundaries
	1	2	3	4	5	
MSS 4	6	41	43	45	60	5
MSS 5	22	46	49	52	104	5
MSS 6	14	45	48	51	108	5
MSS 7	2	20	22	24	63	5

Separation coding boundaries

Groups	Transformed Channels and Reflection Levels	Objects	Features
81	A1 C2 B2 D3 41 48 48 23	Clear Logone river edge	silt-argiles
82	B3 A3 51 45	sandy argiles, dry shrub vegetation, terraces island	sandy argiles
83	D2 C2 A3 22 48 44	low density plots	traditional urban areas

Parameters for controlling aggregation

Groups	Channels			
	MSS 4	MSS 5	MSS 6	MSS 7
81	41,38 1,30	46,44 1,95	47,84 1,69	22,84 1,28
82	44,78 1,33	50,57 1,59	49,89 1,37	23,09 0,93
83	43,85 1,35	48,64 1,58	47,43 1,61	21,86 1,18

Spectral Statistics of Groups.

The method utilized is the same for the division of Group 3.

8.3.2.4 The 9 Groups: Subdivision into two subgroups. /93

Channels	Boundaries 1	2	3	4	5	6	Number of Boundaries
MSS 4	30	39	41	43	60		5
MSS 5	22	39	42	45	48	104	6
MSS 6	14	42	45	48	108		5
MSS 7	2	19	21	23	40		5

Separation of Coding Boundaries

Groups	Transformed Channels and Reflection Levels	Objects	Features
91	A2 B2 39 42	Modern central urban area, dry argiles of bottom lands, dry argiles of low terraces, vegetation in sandy soils	urban area
92	C2 D2 43 20	traditional central urban area with high density	urban area

Parameters for controlling aggregation

Groups	Channels MSS 4	MSS 5	MSS 6	MSS 7
91	39,24 1,25	41,72 2,63	45,29 2,07	21,77 1,29
92	41,68 1,54	45,09 2,13	43,44 1,69	19,76 1,02

Spectral Statistics of Groups

The method used is the same as for the division of group 3.

8.3.3 Legend for Map FOR-3

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The map legend FOR-3, which was printed and presented in the appendix, allows one to locate the various features and their dominating objects, with consideration of the spectral statistics of each group of classification.

Color	Number of Class	Dominant Objects	Features	Spectral Signature			
Blue	2	Chari and Logone rivers, low turbidity water	rivers	39	31	17	4
	4	puddle water, flooded areas, dried up tributaries	puddle water	34	32	30	13
Green	31	Milesi and Kouseri forest, green village, shrub cover	high chlorophyll vegetation	33	30	40	21
	32	Dense shrub of flooded and puddle areas	Chlorophyll vegetation	34	32	37	19
	33	bottom land vegetation and shallow water	vegetation and water	40	38	30	11
	34	bottom land vegetation and low terraces	vegetation	36	34	34	16
	7	modern urban area and humid chlorophyll areas	humid and urban areas	38	39	39	18
Red	91	modern urban areas and river terraces	urban area	39	42	45	22
	92	traditional urban area of high density, sandy argiles	urban area	42	45	43	20

Chestnut Color	5	naga soils, edges of creeks,	sandy argiles	49	58	56	26
	6	low density sub-urban area,	sandy argiles	47	54	52	24
	83	low density sub-urban area	argiles	44	49	47	22
	81	river bank	argiles	41	46	48	23
	82	sandy argiles, dry vegetation,	argiles	45	51	50	23
Yellow	1	sandy banks, sandy river edges	sandy areas	54	65	62	28

Table 8.J. Legend for Map FOR-3 /95

8.4 Sequence of FOR-1.2 Processing, or FOR 1 and FOR 2 Diachrony

We decided to perform a diachronic treatment by superimposing the five measurement channels, that is, the four channels MSS-4, MSS-5, MSS-6, MSS-7 of the data from November 1, 1972, (FOR-1) and the four channels MSS-4, MSS-5, MSS-6, MSS-7 from the data from February 17, 1973 (FOR-2).

8.4.1 The Classification Method in Steps

The classification method in steps assumes that one can perform a spectral character assistance procedure and a feature procedure.

In the case of a diachronic study, the spectral statistics of the groups are particularly interesting factors to be taken into account during the interpretation. From the difference of the forms of the spectra of the two days, one can appreciate the stability of the feature importance of one group over time. This means that one can detect changes in the landscape over time. In the case of LANCHAD, the changes are essentially determined for the variation of the humidity of the ground and the vegetation functions over the year.

We will give three examples of this type of interpretation in Figure

8.K. In the first case, we are dealing with dense forests, (Group 31), whose spectra essentially have the same form for either observation date. The chlorophyll characteristic is dominant and is relatively constant over time. In the second case, we are considering chlorophyll background (Group 33) whose vegetation function changes from November to February. One can see that the reflection spectrum of February is slightly flatter than in November, which translates into a certain drying of the vegetation. In the third case, Group 51, the variation between the two dates is even more distinct. We are dealing with bare and dry sand banks in February, but they are covered with water in November at the beginning of the settling of the Chari and Logone rivers.

The systematic observation of the spectral signatures, therefore, allows us to take into account a diachronic study in the interpretation of the kinematic characteristics.

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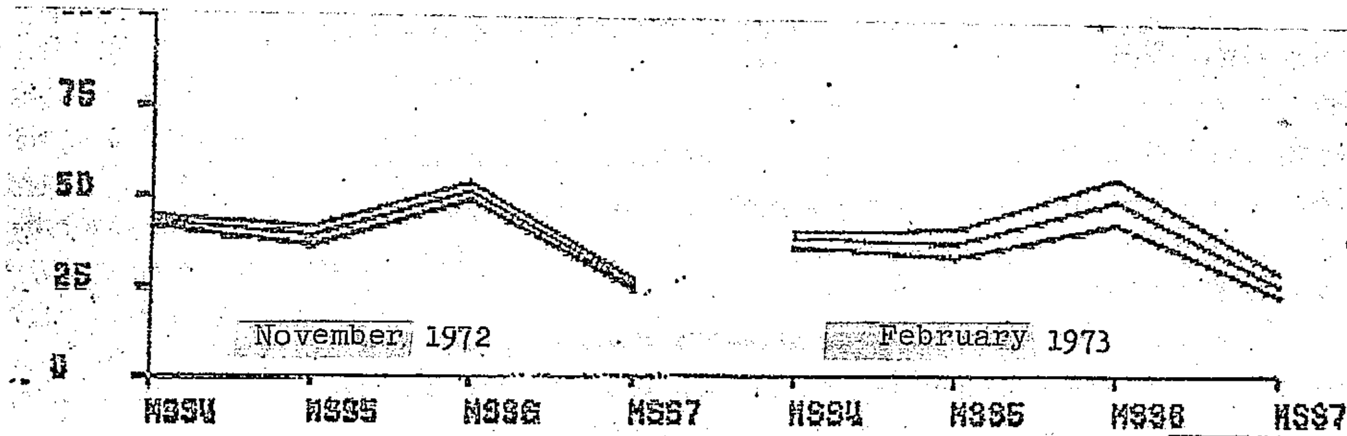
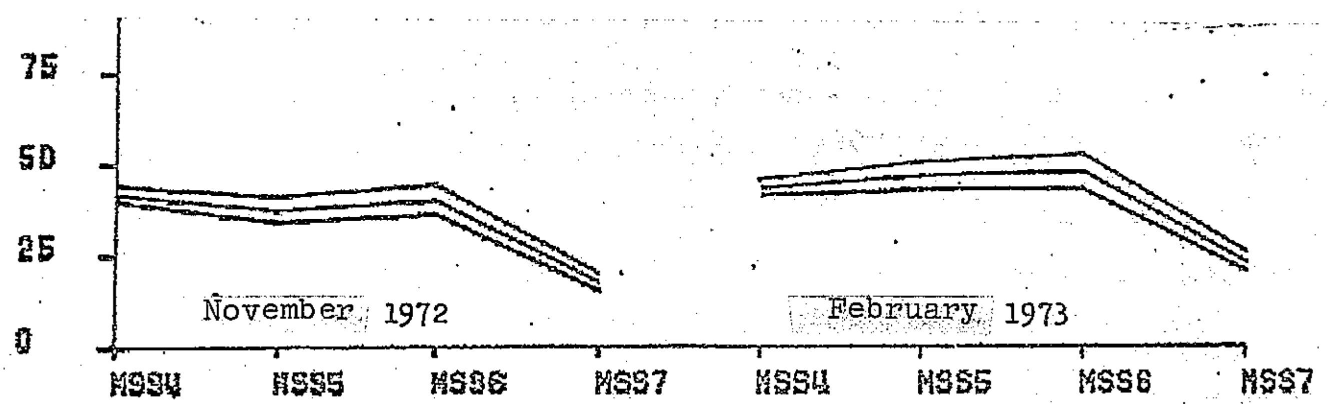
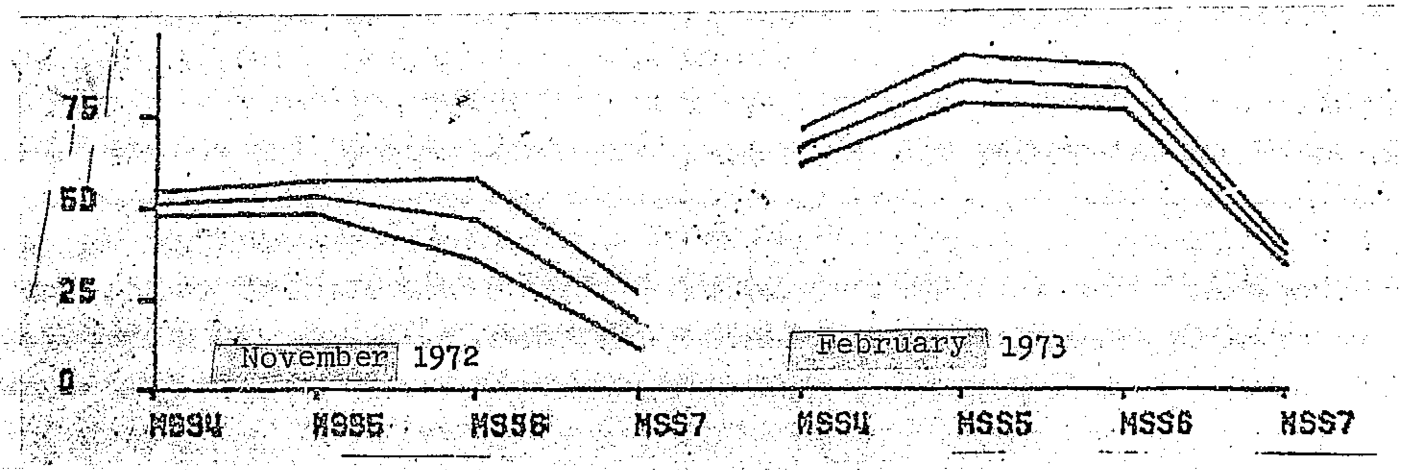


a- Spectral stability of dense forests (Group 31).



b- Drying of chlorophyll bottom lands (Group 33).



c- Rough spectral variation produced by the drying of certain sand-banks (Group 51).

Figure 8.K: Three examples of spectral statistics of the FOR 1.2 diachrony

8.4.2 Classifications of FOR-1.2

	First Classification:		Second Classification
9 Groups	35 groups and subgroups	First Map (3/77) 23 groups and subgroups	Final Map (8/77) 31 groups and subgroups
1	1	1	1
2	21 22 23 24 25	21 + 25 22 23 + 24	21 22 23 + 24 25
3	31 32 33 34 35	31 32 + 35 33 + 34	31 32 + 35 33 + 34
4	41 42 43 44 45 46 47 48	41 42 43 44 + 48 45 + 46 + 47	41 42 43 44 + 48 45 + 46 47
5	51 52 53 54	51 52 53 54	51 52 53 54
6	6	6	61 62 63
7	71 72 73 74 75 76	71 72 + 73 + 75 + 76 74	71 72 73 74 75 + 76
8	81 82 83 84	81 + 84 82 + 83	81 + 84 82 + 83
9	9	9	91 92 93

8.4.3 Legend of Map FOR 1.2

The final legend for Map FOR 1.2 given in the appendix allows one to identify the various features and their main objects, with consideration of the spectral statistics of each group of classifications. This legend is described in the following table:

Table 8.L: Legend of Map FOR 1.2

Color	Class Number	Dominant Objects	Features	Spectral diachronic four channel signature			
Blue	42	deep rivers, low turbidity, on the bottom	rivers	50	31	11	3
	45+46	shallow rivers, decreasing turbidity toward the bottom	rivers	50	36	12	6
	47	river banks and puddle centers during drying	rivers	48	44	12	15
	44 + 48	puddles drying up	puddle water	37	37	17	17
	41	vegetation on puddle waters during drying	water and vegetation	35	34	19	18
	43	argile depression, vertisols humid to high chlorophyll content	argile bottom lands	48	39	23	18
Green	31	Milesi woods, Kousseri woods, IZVAC gardens, parks, forests	high chlorophyll vegetation	38	36	25	25
	32+35	high chlorophyll puddle area shrubs, ponds	chlorophyll vegetation	36	39	22	22
	33+34	bottom lands and old tributaries, very humid and high chlorophyll, cultivated	chlorophyll bottom lands	41	43	20	20
	1	flooded areas drying up with dry vegetation	depressions and flooded zones	51	60	21	27

	74	Humid argile and chlorophyll areas drying up	terraces	48	55	26	27
	22	Residential areas, green villages, drying tendency	urban area, green village	45	49	25	26
	23+24	flooded areas to planted areas	flooded areas	52	47	25	21
Red	72	urban areas and islands with modern construction	modern urban areas	55	50	26	24
	71	traditional central high density area	traditional urban area	60	52	26	23
	82+83	traditional low density areas and suburban areas	suburban area	64	61	29	28
	92	suburban low density area with bare areas	suburban area, sandy argiles	62	61	28	27
Chestnut color	61	river banks and terraces to cultivated areas	riverbanks	66	62	30	28
	62	riverbanks and creeks and nagas, to cultivated areas.	nagas and riverbanks	72	64	31	28
	63	urban areas and riverbanks to dry areas, suburban areas	bare argiles, sandy areas	64	65	29	29
	91	terraces and riverbanks	sandy argiles	49	61	24	28
	93	riverbanks to dry areas	sandy argiles	56	62	26	28
	73	suburban and riverbanks	sandy argiles	55	55	26	25
	75+76	riverbanks and cultivated terraces	sandy argiles	53	57	24	21
	21	riverbanks and cultivated terraces	terraces and riverbanks	49	51	23	23
	25	argile sandy areas to dry areas	terraces	49	51	23	23

	81+84	bare and dry areas, sub-urban areas, (Milesi, Chagoua, Denibe)	suburban areas, bare spaces	60	60	27	27
Yellow	51	Dry and bare sandbanks on the second date, and covered by water on the first date	banks and sand	53	19	84	40
	52	banks and riverbanks uncovered by settling	sandy ar-gile silts	50	22	70	32
	53	very dry and bare sands on both dates	sandy argiles	72	31	72	32
	54	sandy riverbanks and halomorphic soils	nagas and riverbanks	60	28	68	31

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The eight channels are numbered in the order 1, 2, 3, 4, 5, 6, 7, 8. MSS-5 on the first date is Channel (2), MSS-5 on the second date is channel (6). MSS-7 of the first date is channel (4), and MSS-7 on the second date is channel (8).

8.5 Correspondence of Legends of Classifications FOR 1, FOR-2, FOR 3, and FOR-1.2.

This correspondence will be analyzed in a subsequent study, which will take into account the truth-terrain data.

This correspondence table is therefore preliminary. The variation of the spots with time, therefore, is a very complex phenomenon which can not be easily described. In a subsequent publication, the study will consider the diachronic variation of the spots within the features.

Color	Features	FOR 1	FOR 2	FOR 3	FOR 1.2
Blue	Water	3 22 21	1 33 34	2 4	42 45+46 47 44+48 41 43
Green	Vegetation	23 24 52 51 53	31 32	31 32 33 34 7	31 32+35 33+34 1 74 23+24 22

Color	Feature	FOR 1	FOR 2	FOR 3	FOR 1.2
Red	urban areas	42 44 56 55	5 61 62 73 74	5 6 83 81 82	72 71 82+83 92
Chestnut color	argiles to sandy argiles	42 44 56 55	5 61 62 73 74	5 6 83 81 82	61 62 63 91 93 73 75+76 21 25 81+84
Yellow	sandy to sandy argiles	1 41	2 4	1	51 52 53 54

CHAPTER 9 GEOGRAPHIC AND CARTOGRAPHIC INTERPRETATION

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The geographic interpretation of the results of classification for the maps presented here should be essentially based on the specific features of the landscapes observed on the recording dates by the LANDSAT satellite.

The detailed geographic analysis of the results will be the topic of a separate publication, and there will be a certain delay with respect to the numerical analysis. This will allow a comparison of the detailed results, and the totality of the information collected during ground truth surveys.

We would like to stress that for the Sahara-Sudan environment, the variation of the surface phenomena related to the water cycle and to the vegetation cycle is extremely rapid. During the two observation dates by the LANDSAT satellite, for example, between November 1, 1972, and February 17, 1973, one finds completely opposite times during the water and vegetation cycles observed on the ground. Considering the orbital variations, the pixel density (80 m x 80 m) will probably be difficult to superimpose between the two dates. The variation of the spectral signatures of the pixels is a complex phenomenon related to the size of the observed objects and the increasing or decreasing diffusion of objects located within the pixels.

A few specific features can be described as an example.

9.1 Traditional Urban Area Feature

The traditional poto-poto habitation feature can or cannot include the following:

- tile roofs
- a tree in the yard
- a larger or smaller yard
- a poto-poto enclosure wall
- cases with seco (thatch) roof.

The traditional habitation islands can be limited by very narrow streets or can include areas of habitation which are widely dispersed over bare ground without enclosures or fences. This is what we will call traditional habitation areas with high density or with low density.

9.2 Modern Urban Area Features

Modern constructions for habitation or other purposes can be constructed in high-density areas or in parks and gardens.

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The streets can be tarred or can be simple tracks. The avenue can be bare or have tree borders. The tiled roofs or concrete terraces can be partially covered by the branches of large trees, or can reflect greatly from bare ground.

In the two cases, traditional areas or modern areas, the soil can be saturated with water or can be completely dry.

9.3 Rural Landscape Feature

These features are known from pedological maps, or vegetation maps, with scales between 1:200:000° to 1:500,000°. In these maps, division into zones results in two generalizations. The aerial surveys available come from different dates.

The results of the classification of the numerical LANDSAT satellite data allow a very detailed approach to this type of environment; for example, large variations in the ground reflection were observed, depending on the variation of the cultural cycle. The chlorophyll effect can dominate, depending on whether the water layer in the ground has already (or not yet) allowed the appearance of shrub vegetation. It also depends on the seasonal cycle variations of natural vegetation, and whether or not this leads to a detectable chlorophyll effect. The variation of the chlorophyll effect is very rapid for the following, for the Sahara-Sudan environment:

- the forest galleries of the berger riverbanks,
- the shrub and pine foliage
- low density acacia or mimosa areas,
- low areas covered with shrubs with andropogoneous vegetation
- burned-over cultivated areas
- rainy cultivated areas
- pond cultivated areas.

9.4 <u>Cartography at the scale of Territory Management</u>

The cartography presented here on the scale of 1:50,000° and 1:100,000° shows the possibility of working at scales which are useful for managing territories, using numerical data from the LANDSAT satellite. This thematic analytic cartography must be followed by thematic cartography which is more synthetic and represents the step of geographic interpretation of results. This is done at a separate time.

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We can only present the results of this synthesis work when the analytic cargotraphic works for the three 1975 and 1976 images appear for the same zone (FOR 4, FOR 5, FOR 6).

The synthesis will therefore be the result of multiple season and multiple year analyses which we have performed. We believe that this is the only way of performing research in this area.

CHAPTER 10 - LANCHAD PERSPECTIVES FOR THE PLANNED ANALYSIS OF THE SAHARA-SUDAN ENVIRONMENT /105

The LANCHAD atlas is one of the important tools for the analysis of the natural geographic environment or the cultivated environment in an area which extends from 7°N to 24°N and 12°E to 25°E. This is approximately 2,500,000 km^2.

This project has been presently proposed to the assistance and cooperation fund by the Tchad ministry of the economy. It is planned that a reference document will be prepared for managing the territory.

The types of terrain which are planned to be analyzed are the following, within the framework defined by these six parts of the regional Tchad atlas:

Part 1: Bardai Oasis, Pic Tousside, Emi Koussi; Faya Oasis, Ounianga Oasis, Sahara region.

Part 2: Mao Oasis and Diwe basins, Ouadi cultures, pastures; Liwa and sodium depressions;
Bol Polders and Chari delta;
Sahelia region.

Part 3: Djamena zone, urbanization and farms; deforestation due to urban economy; Bongor and rice plantations; Sahelia-Sudan area

Part 4: Lai and Tandjile rice plantation, Sategui-Deressia; Moundou, Gounou Gaya, cotton fields; Pala, Fianga, Lere, mining area; Goundi, Dono Manga, Doba, Koumra, les Koros, le Mandoul; the tropical Sudan area.

Part 5: Sarh, Moissala; Am-Timam, Haraze Mangueigne, le Salamat, cotton plantation, sugar cane, peanuts, explotation of the the Karite region

Part 6: Abeche, Ati, Mongo; peanut plantations, ouadi cultivation, pasture.

In each part, the dynamic analysis of the area will be directed by the condition of providing the useful and new information, capable of supporting major management decisions of the territory within the general project of development of the Tchad up to 1980.

The following topics will be discussed: /106

- urbanization and effect of urban economy on the area,
- traditional and modern agriculture,
- agriculture and industrialization, cotton, rice, peanuts
- arborculture and forestry
- erosions of the ground
- geology and geomorphology
- hydrogeology and hydrology,
- study of regions and territories
- use of various soil areas.

Considering the remote detection methods used, it is predictable that their number and their capacity will overlap.

As far as the wavelength is concerned, we would like to state that in 1978 the LANDSAT-D satellite will allow operation in the thermal infrared range (10 to 12 M) with a resolution comparable to that of the present LANDSAT satellites. This new possibility will allow a detailed study of the evaporative transferation of the vegetable growth. This is an essential factor for a good definition of cultivation.

As far as the repetitiveness of the observations in time is concerned, there will be a substantial change in 1978 because of the launching of the European METEOSAT satellite. This will allow double observations in the visible and infrared ranges, with a resolution of about 1 km with a potential repetitiveness of 1 observation every 30 minutes, day and night. This will mean that for the first time the Tchad will be observed during various seasons, in particularly, the rainy season. The accumulation of images during one day will allow the elimination of the massive cloud cover. The clouds are displaced rapidly enough during one day so that they do not cover the same part of the country over a period of 24 hours. There will also be substantial improvement in the areas of geology and hydrogeology, in particular, the temperature differences on the ground as a function of the time of day and night will be valuable. The variation of these very differences will depend on a parameter called the thermal inertia, which is directly related to the characteristics of the rocks and the humidity

flux in the soil.

The multiplicity of these new observations will mean that we will have to establish a reference data bank showing ground truth values for each of the topics of this project. In this case, recourse to the information is a requirement considering the complicated processing of the data from remote sensing.

LIST OF ABBREVIATIONS /107

AEF - French Equitorial Africa
APT - Automatic Picture Transmission
ASECNA - Association for Airborne Navigation Safety
CEMS - Center of Space Meteorological Studies
CERCG - Study and Research Center for Geographic Cartography
CIRCE - Interregional Center of Electronic Calculations
CNRS - National Center for Scientific Research
CTAMN - Remote Detection Center and Analysis of Natural Media
DMG - Directorate of Mines and Geology of the AEF
EHESS = Advanced Social Science School
ENSJF - Advanced Normal School for Young Girls
ENSMP - National High School of Mines in Paris
ENTP - National Public Works School
EPHE - Practical Advanced School
ERTS - Earth Resources Technology Satellite
ESCG - Advanced Geographic Cartography School
FAC - Aid and Cooperation Fund
IGNF - National Geographic Institute of France
IRC - Infra-Red Color
MICA - Ministry of Industry, of Commerce and Artistry
NOAA - National and Oceanic Atmospheric Administration
ORSTOM - Scientific Research and Technical Office for Overseas
Pixel - Picture Element
RCP - Operative Research on the Program
STISI - Data Processing and Statistical Industrial Service

LIST OF MAPS, FIGURES, PLATES, AND TABLES

- Map FOR 3 - N-Djamena, 1:50,000°, January 12, 1973, image E 1173 08513, printed by CNRS, October, 1977
- Map FOR 1.2, N'Djamena, 1:50,000°, diachrony FOR-1 FOR-3, printed by CNRS, October, 1977
- Geographic Taxonomy, of the N'Djamena-Kousseri area at a scale of 1:100,000°, according to the generalized classification of FOR 3; map printed at the National High School of Mines at Paris; (CTAMN), October, 1977
- image of the LANDSAT at the N'Djamena zone, sketch at a scale of 1:500,000°, location of involved areas.

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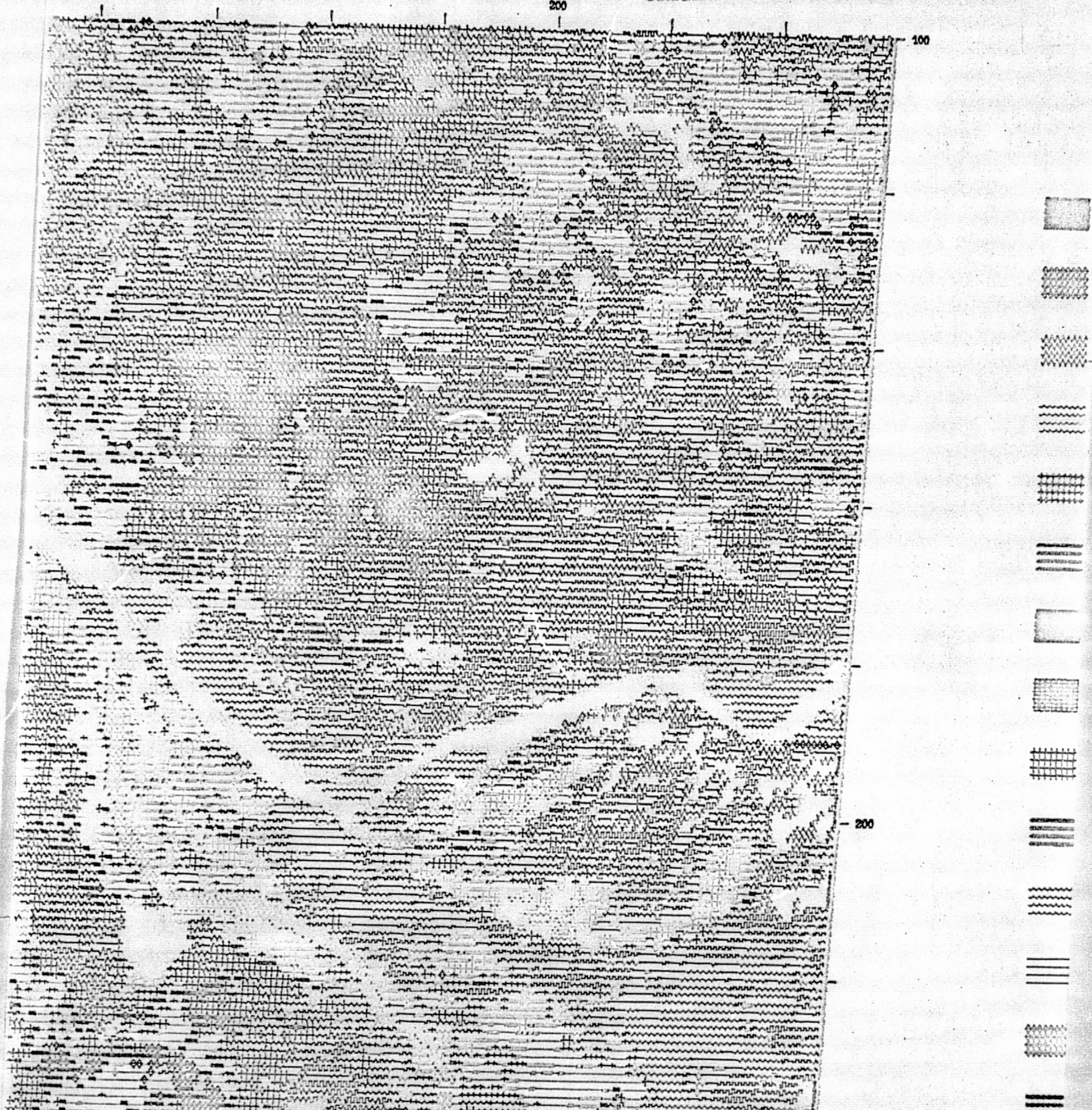
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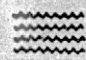
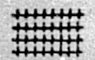
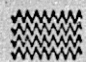
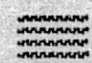
560	2.53	42		3209	14.49	61.75.76
915	4.13	45.46		573	2.59	62
306	1.38	47		1102	4.97	63
869	3.92	44.48		1086	4.90	91
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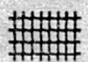
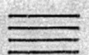
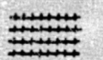
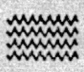
514	2.32	43		3092	13.96	73
216	0.98	31		1066	4.81	21
918	4.14	32.35		1900	8.58	25
571	2.58	33.34		1816	8.20	81.84
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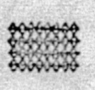
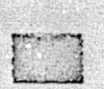
1330	6.00	74		661	2.98	53
2708	12.22	23.24		1181	5.33	54
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Atlas Lanchad, N/Djamena, 1/50,000 - FOR 1

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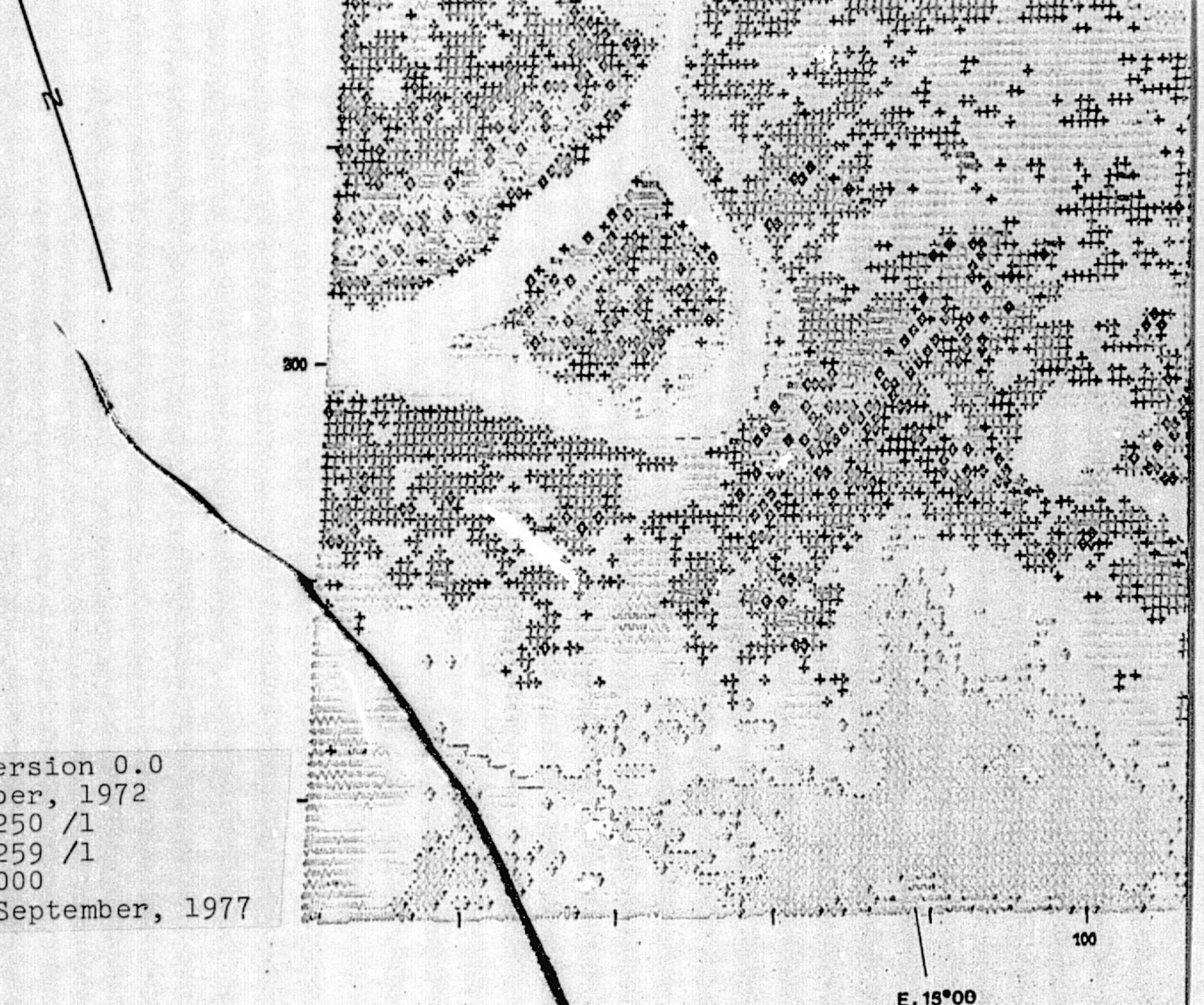

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Produced in September, 1977

Paris University - Tchad University
Interuniversity Agreement
LANCHAD Atlas - Regional Tchad Atlas

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FOLDOUT FRAME 1

Image LANDSAT 1 011172-1101-085152

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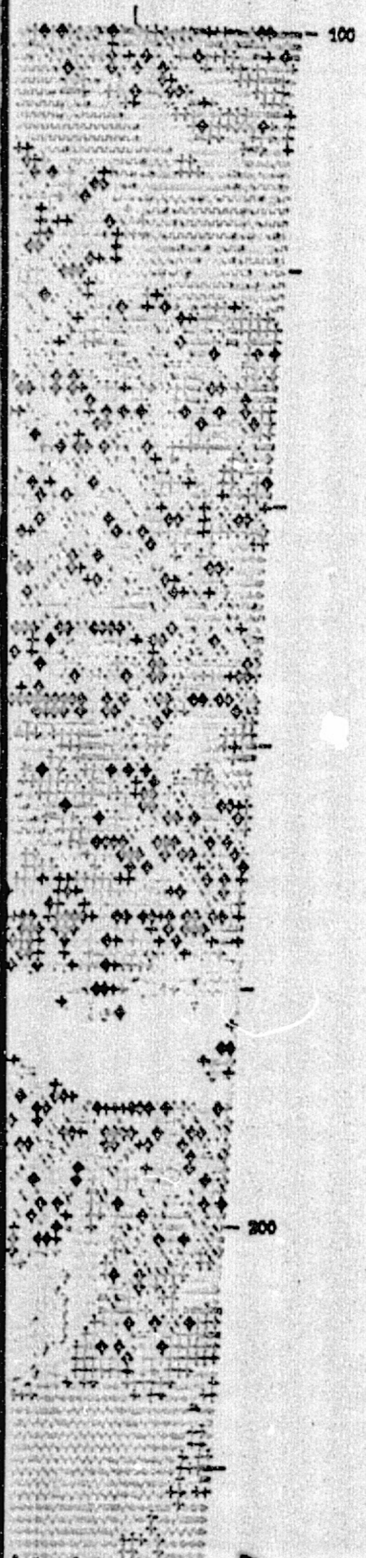

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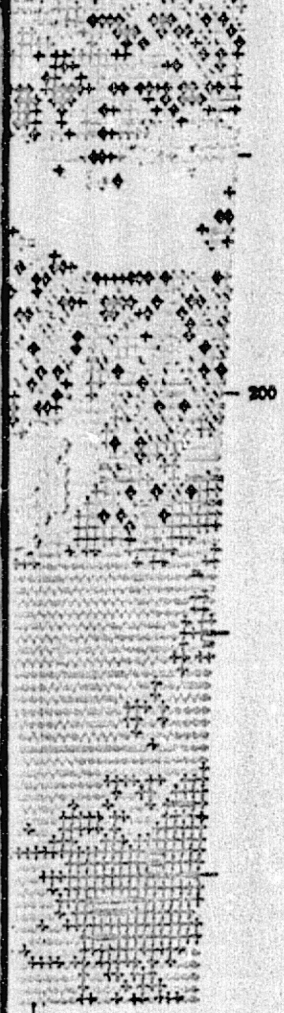

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	3109	14.03	43
	2133	9.63	54
	1733	7.82	42
	2932	13.24	44
	5344	24.12	56
	3350	15.12	55
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	2022	9.13	41

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Imprimé au C.E.R.C.G. du C.N.R.S.
octobre 1977

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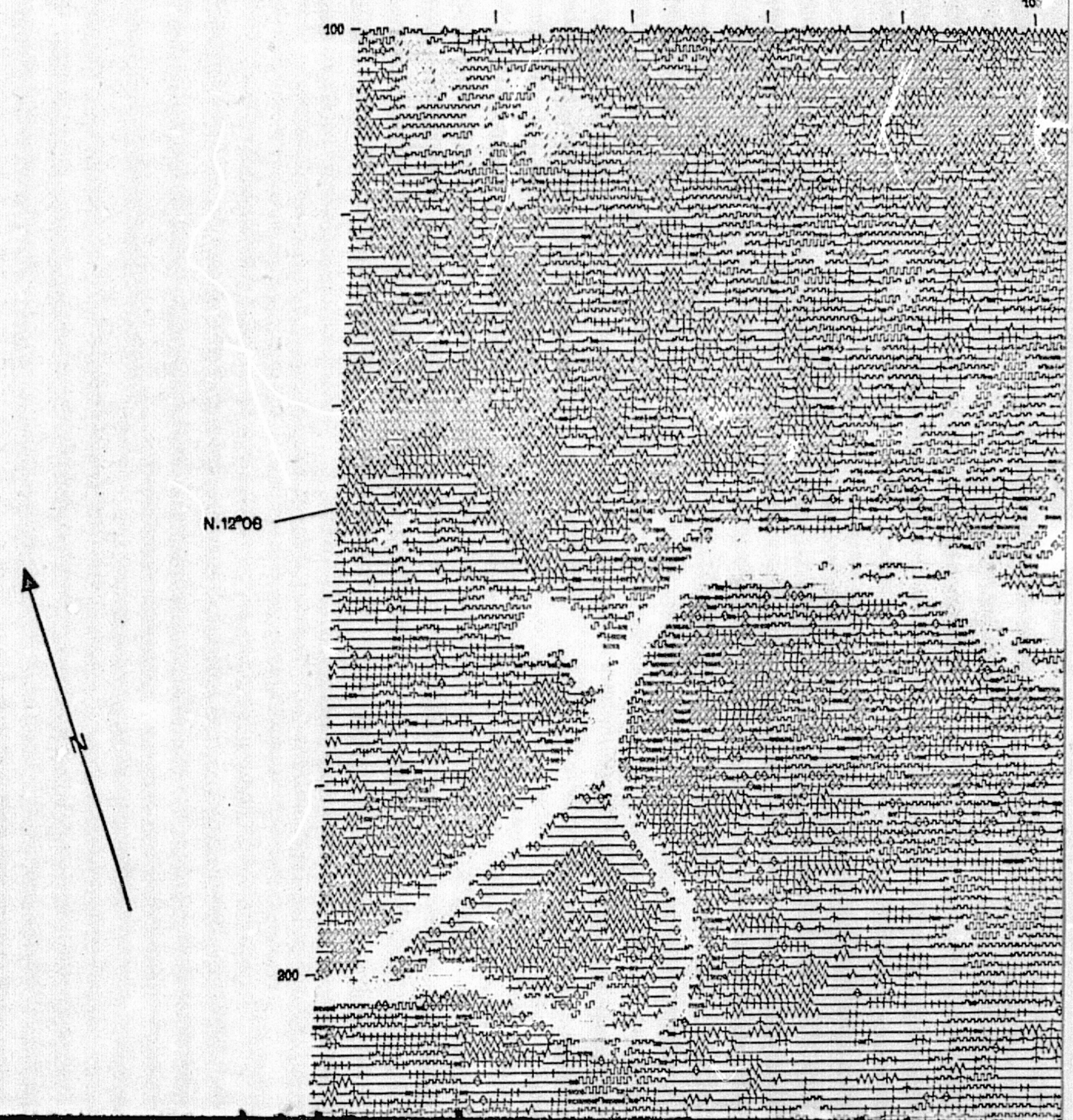
Atlas Lanchad, N'Djamena, 1/50,000 - FOR 2
LANDSAT images 1 170273-1209-08521



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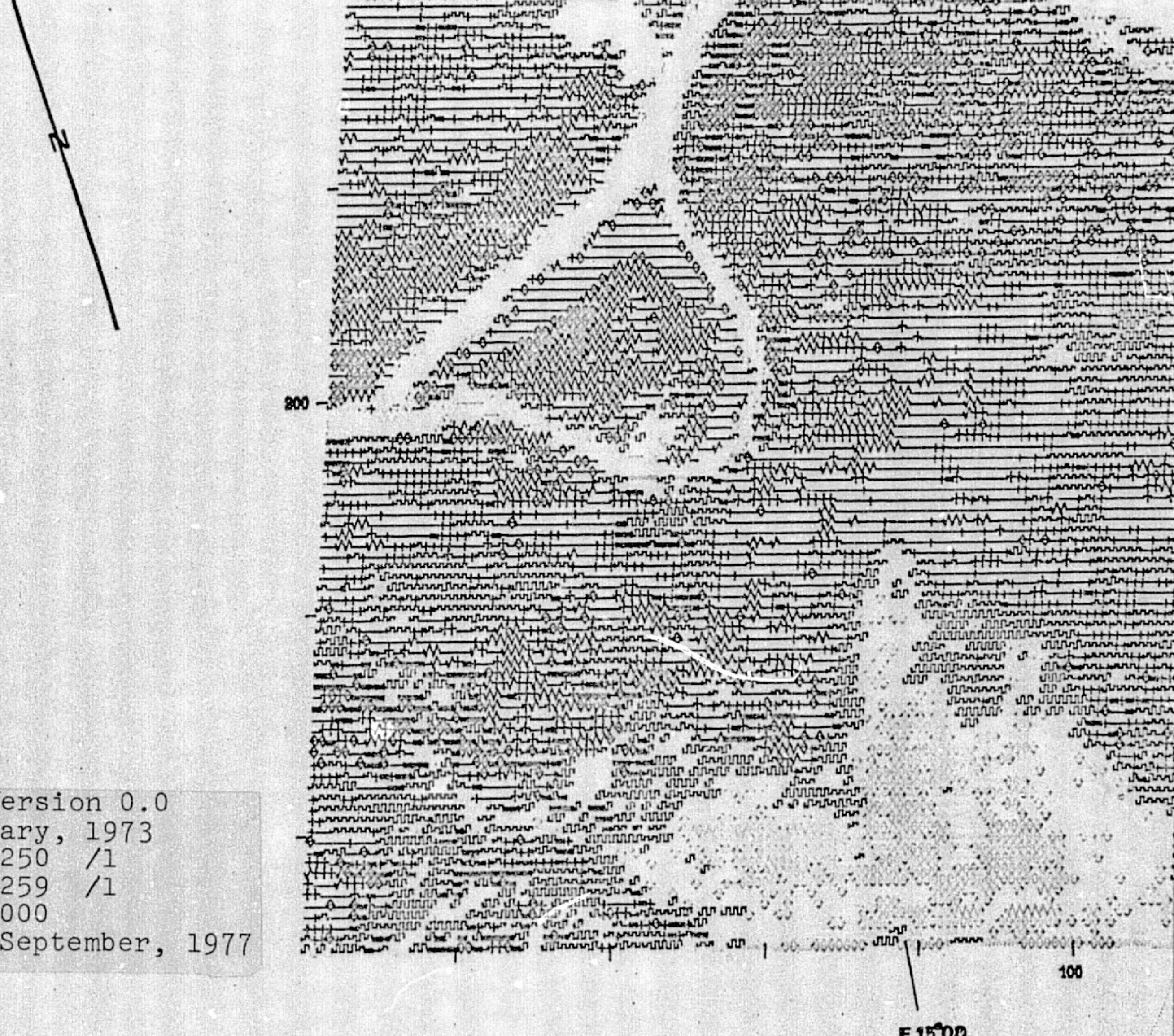


Fracarte - Version 0.0
FOR 2, February, 1973
Lines 100 A 250 /1
Columns 1 A 259 /1
Scale: 1/50,000
Produced in September, 1977

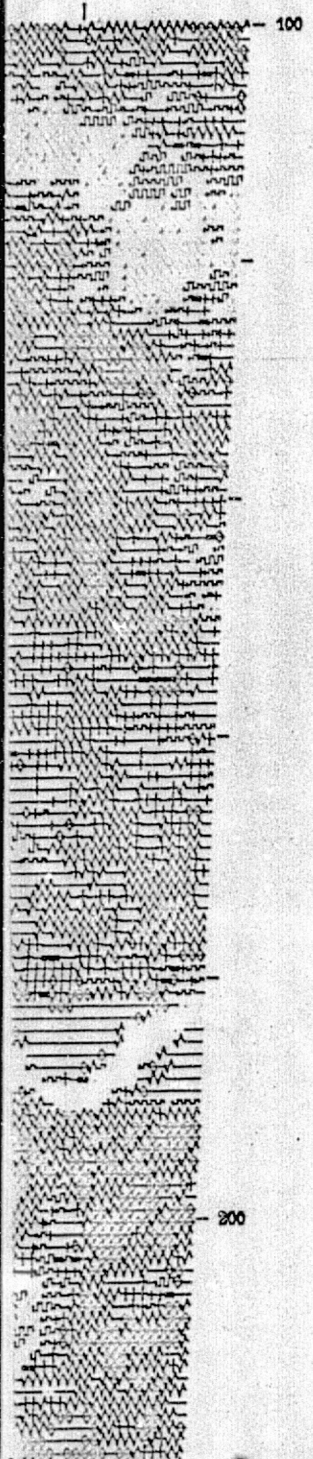
Paris University - Tchad University
Interuniversity Agreement
LANCHAD Atlas - Regional Tchad Atlas

FOLDOUT FRAME 2

FOLDOUT FRAME 1

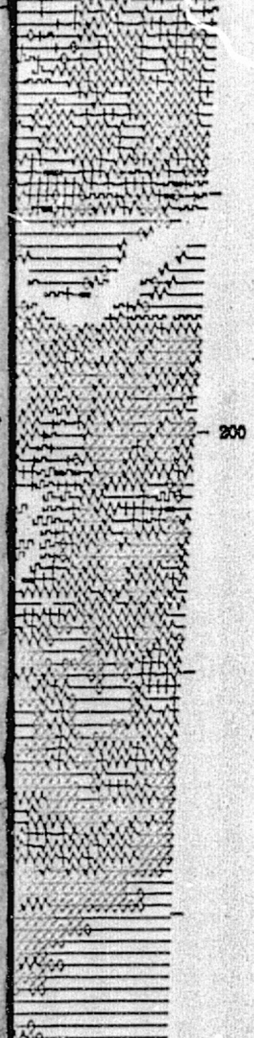

200
200

FOLDOUT FRAME



Geographic Feature Legend

number of characters	area in km^2	class number
917	4.14	1
695	3.14	33
1086	4.90	34
1327	5.99	31
1435	6.48	32
1101	4.97	72
3979	17.96	71
8759	39.54	63
6047	27.30	5
2780	12.55	61
1148	5.18	62
1649	7.44	73

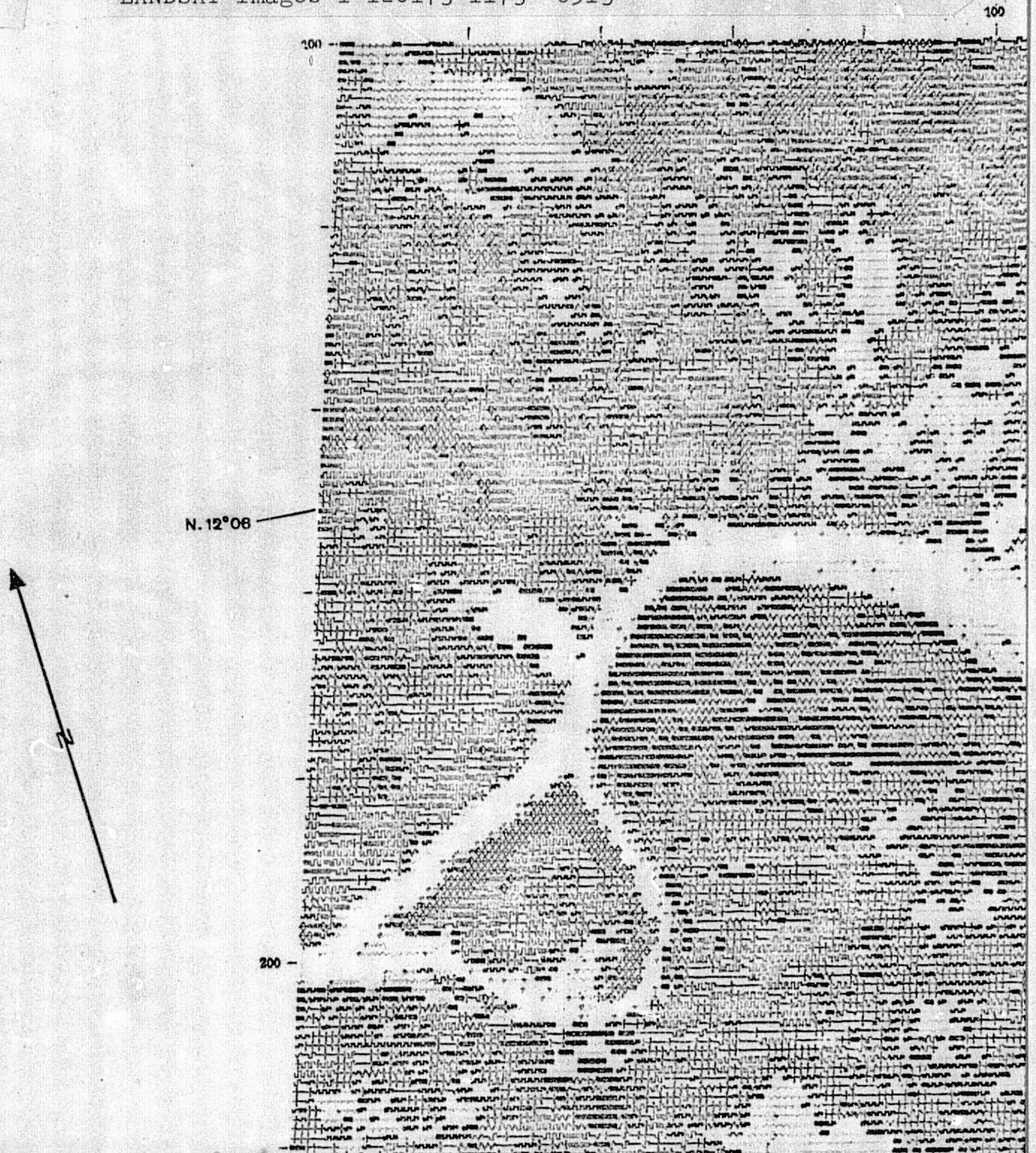


	1101	4.97	72
	3979	17.96	71
	8759	39.54	63
	6047	27.30	5
	2780	12.55	61
	1148	5.18	62
	1649	7.44	73
	4021	18.15	74
	977	4.41	2
	3188	14.39	4

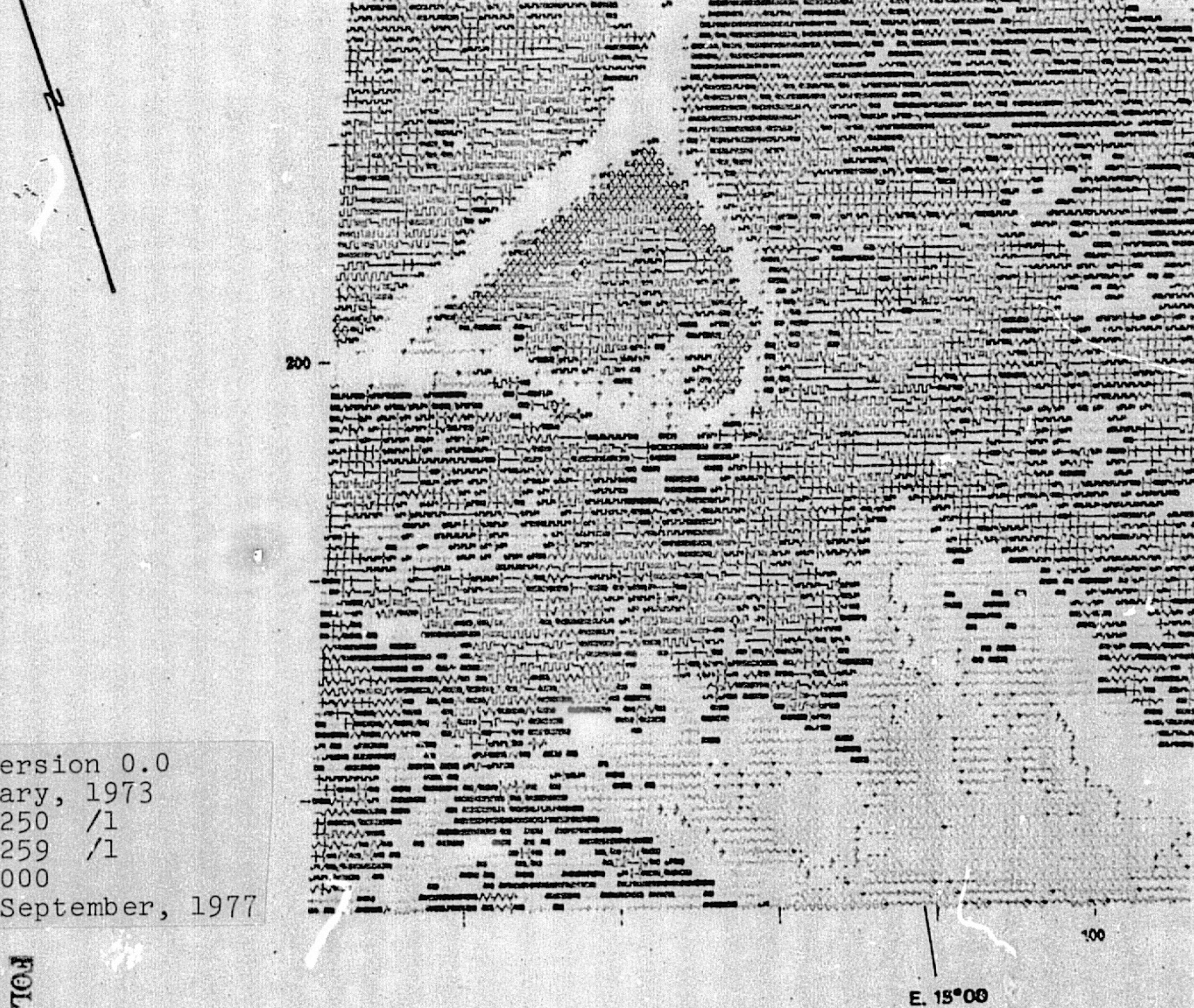
FOLDOUT FRAME 2

Imprimé au C.E.R.C.G. du C.N.R.S.
octobre 1977

Product of the Team Fralit - L. Bardinet, J. M. Monget - 1977
Atlas Lanchad, N'Djamena, 1/50,000 - FOR 3
LANDSAT images 1 120173-1173--8513



FOLDOUT FRAME

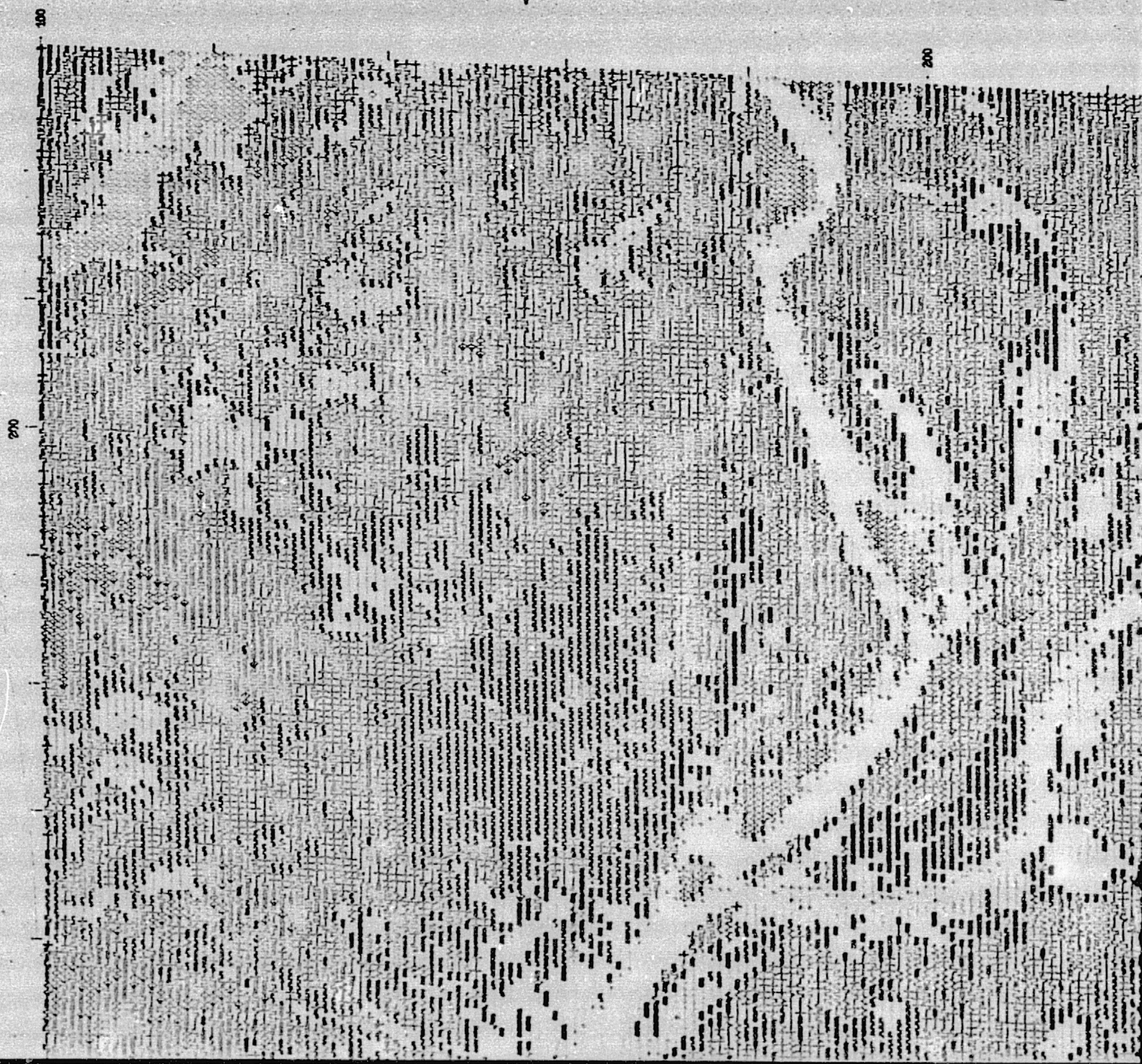


Fracarte - Version 0.0
FOR 3 = January, 1973
Lines 100 A 250 /1
Columns 1 A 259 /1
Scale: 1/50,000
Produced in September, 1977

FOLDOUT FRAME 2

Paris University - Tchad University
Interuniversity Agreement
LANCHAD Atlas - Regional Chad Atlas

FOLDOUT FRAME 1



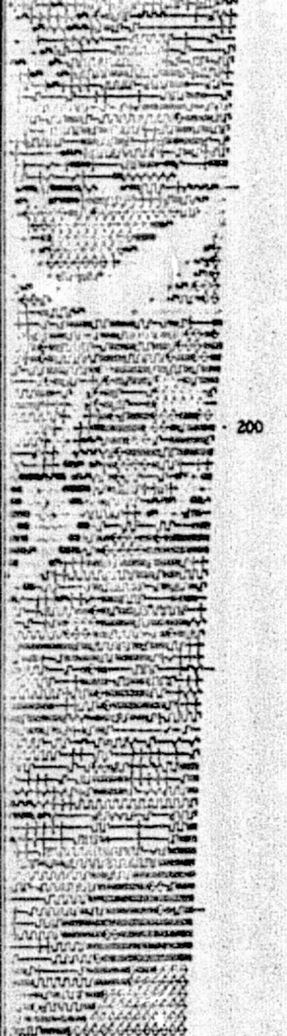
 2

REPRODUCIBILITY OF THE
ORIGINAL PAGE

Geographic Feature Legend

number of characters	area in km^2	class number
1252	5.65	2
1691	7.63	4
523	2.36	31
560	2.53	32
551	2.49	33
1029	4.64	34
3509	15.84	7
3135	14.15	91
4918	22.20	92
3035	13.70	5
5693	25.70	6
6420	28.98	83

FOLDOUT FRAME



	1029	4.64	34
	3509	15.84	7
	3135	14.15	91
	4918	22.20	92
	3035	13.70	5
	5693	25.70	6
	6420	28.98	83
	2198	9.92	81
	3349	15.12	82
	1246	5.62	1

FOLDOUT FRAME 2

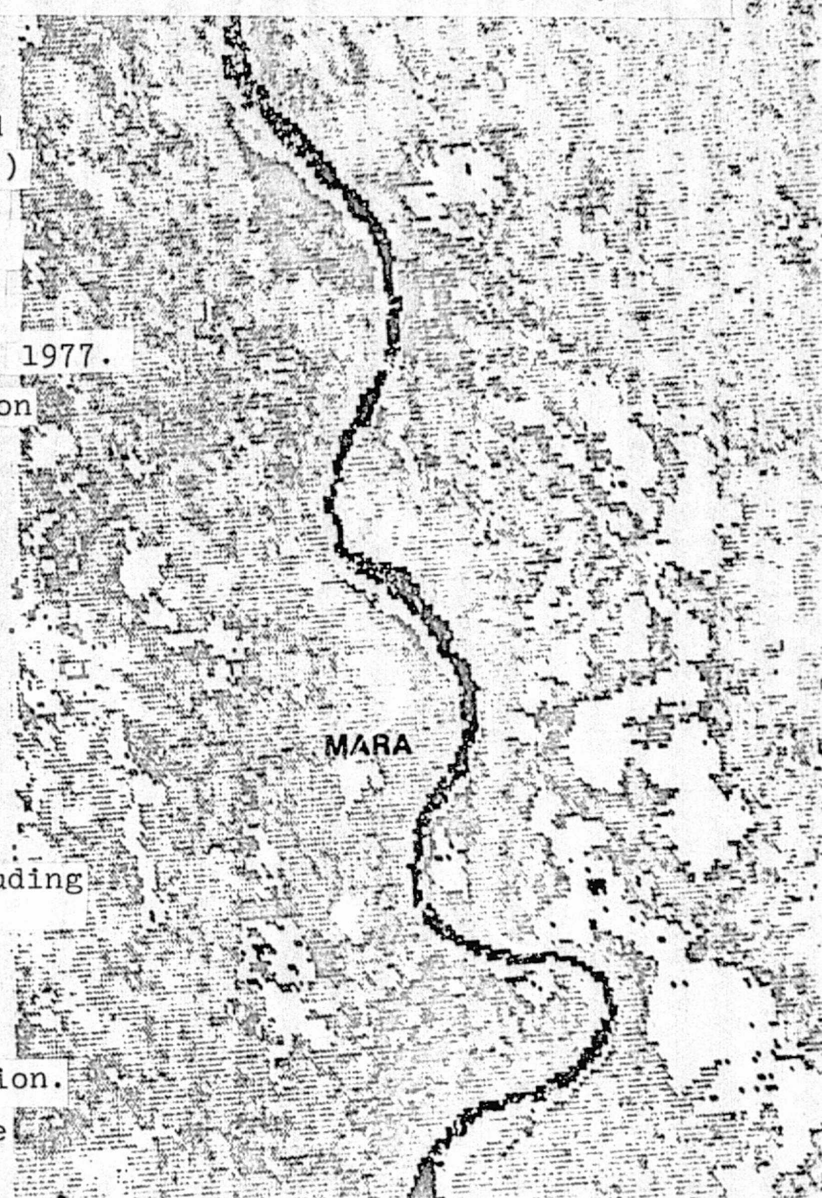
Imprimé au C.E.R.C.G. du C.N.R.S.
octobre 1977

Remote sensing and medium analysis center of the Advanced Mining School at Paris, Sophia, Antipolis - 06560 Valbon.

GEOGRAPHIC TAXONOMY OF THE N'DJAMENA-KOUSSERI AREA. TCHAD REPUBLIC, UNIFIED REPUBLIC OF CAMEROON.

Lanchad Atlas - FOR 3

Map produced from LANDSAT 1 EROS DATA CENTER - E-1173 - January 12, 1973.



LEGEND:

Document produced with the aid of the Cooperation Ministry (F.A.C.) and in collaboration with the Paris University and the Chad University within the Fralit team cooperation. (M. Albuisson, C. Bardinet, J. M. Monget), Sophia Antipolis, October, 1977.

Data selection in the classification FOR 3

Color	MSS7	MSS5	MSS4	Features
Black	0-7	24-127	X	River
Green	17-27	20-67	X	Vegetation
Red	0-16	X	20-46	Burnt-over area
Yellow	28-63	X	0-147	Sand
White	X	X	X	Others including puddles.

The darker the color values:

- for green, the greater the chlorophyll content of the vegetation.
- for red, the more recent the burnt-over areas are.

FOLDOUT FRAME

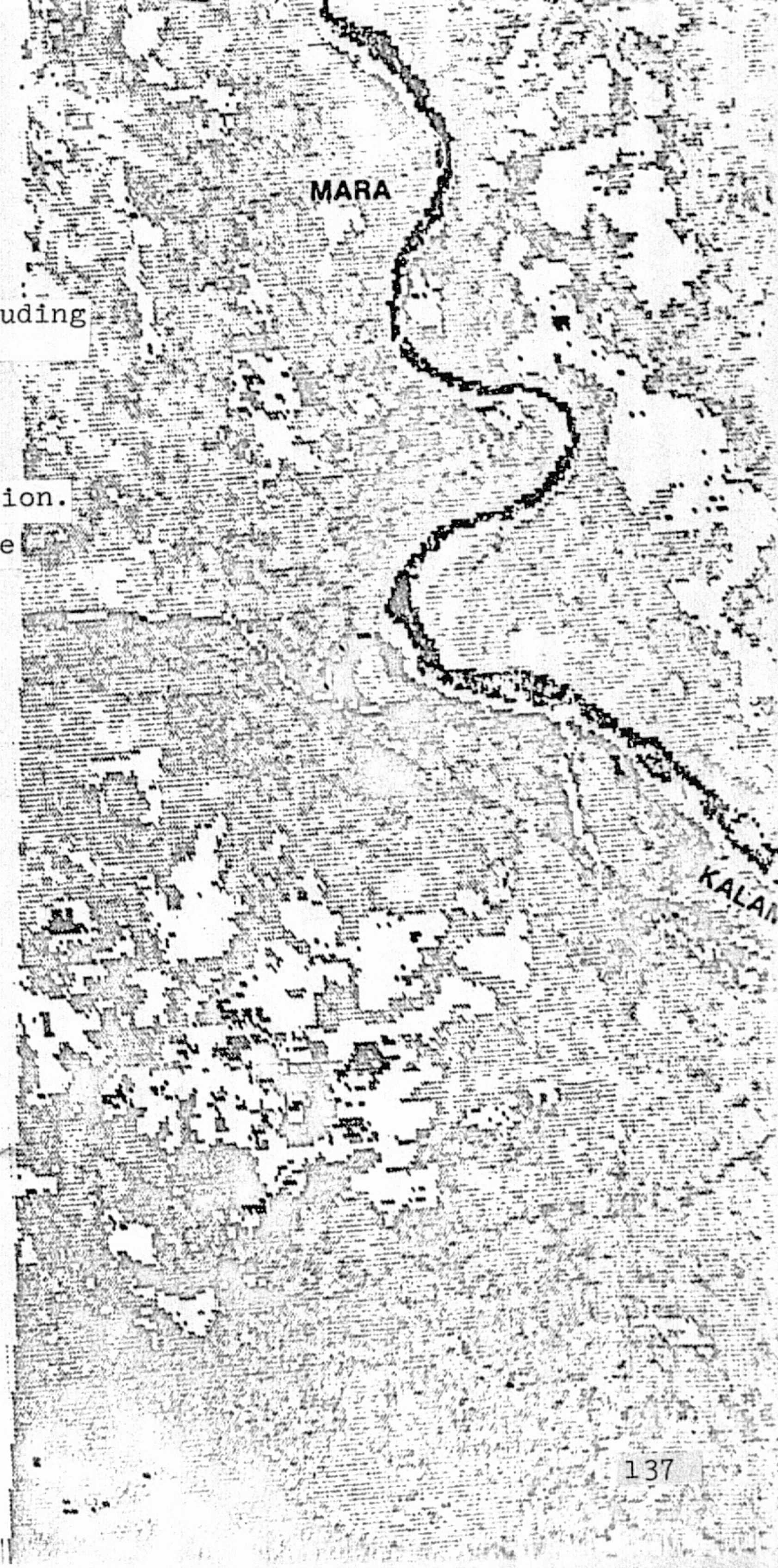
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Black	0-7	24-127		River
Green	17-27	20-67		Vegetation
Red	0-16		20-46	Burnt-over area
Yellow	28-63		0-147	Sand
White				Others including puddles.

The darker the color values:

- for green, the greater the chlorophyll content of the vegetation.
- for red, the more recent the burnt-over areas are.

Scale: 1/100,000

North



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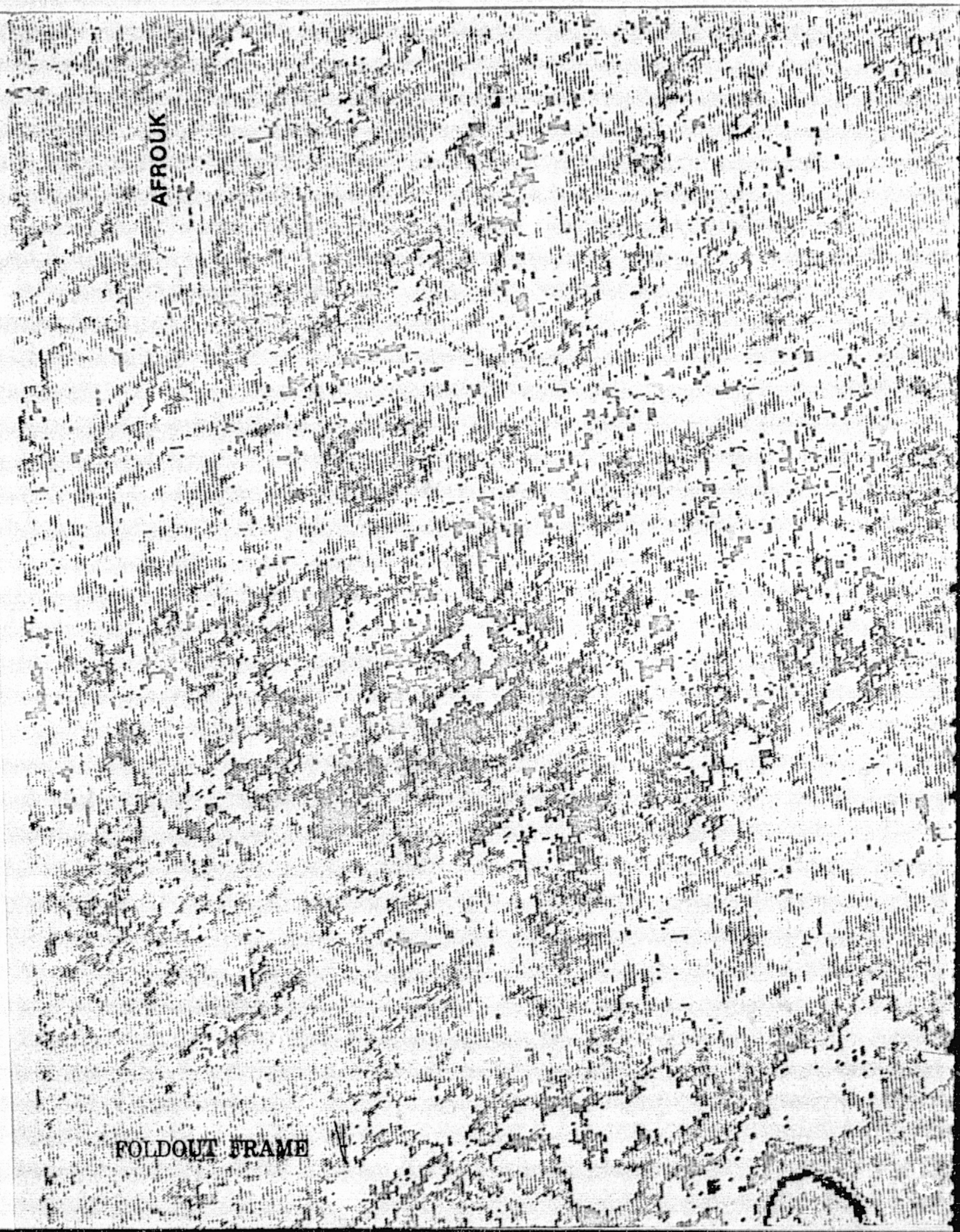
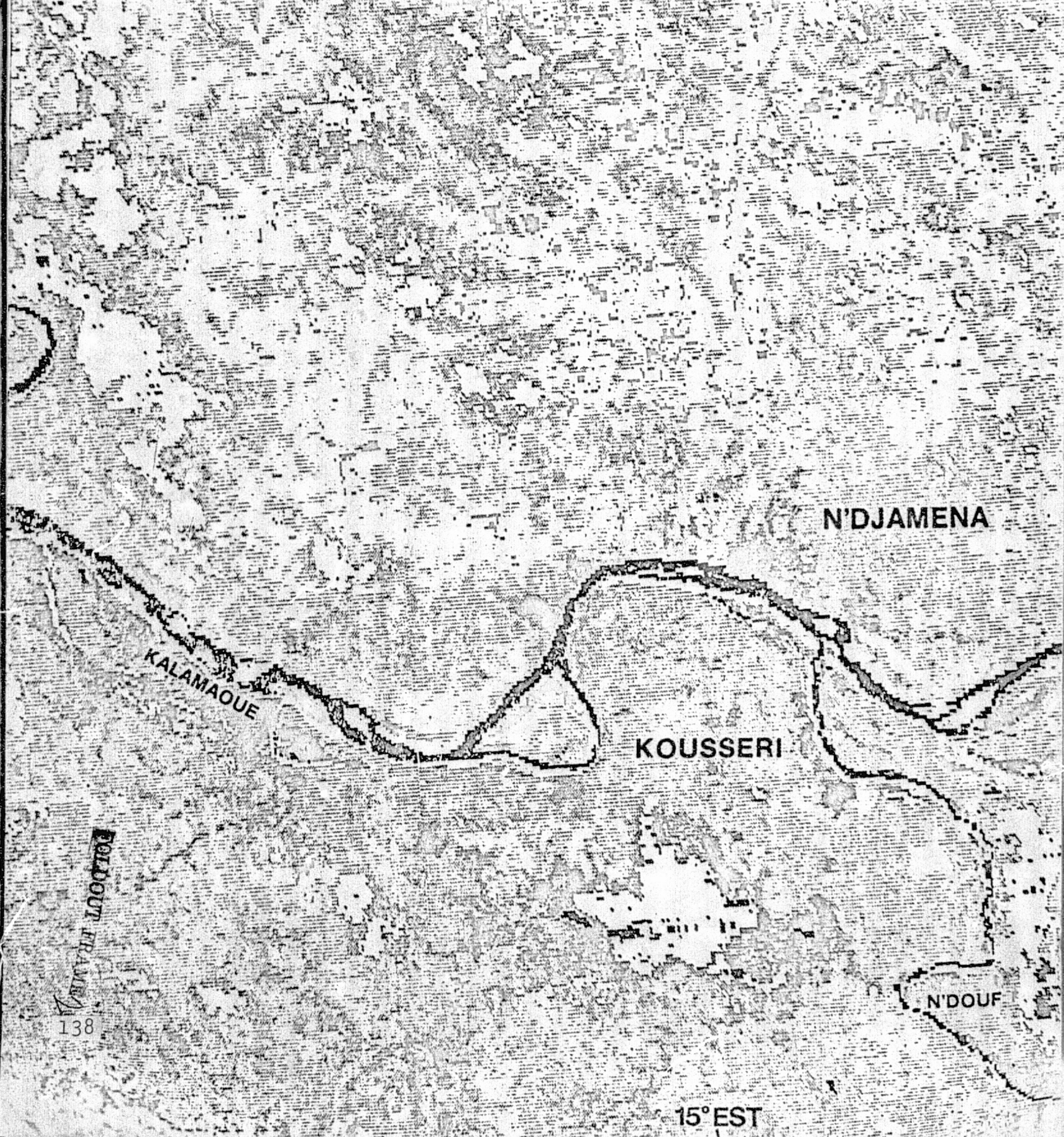
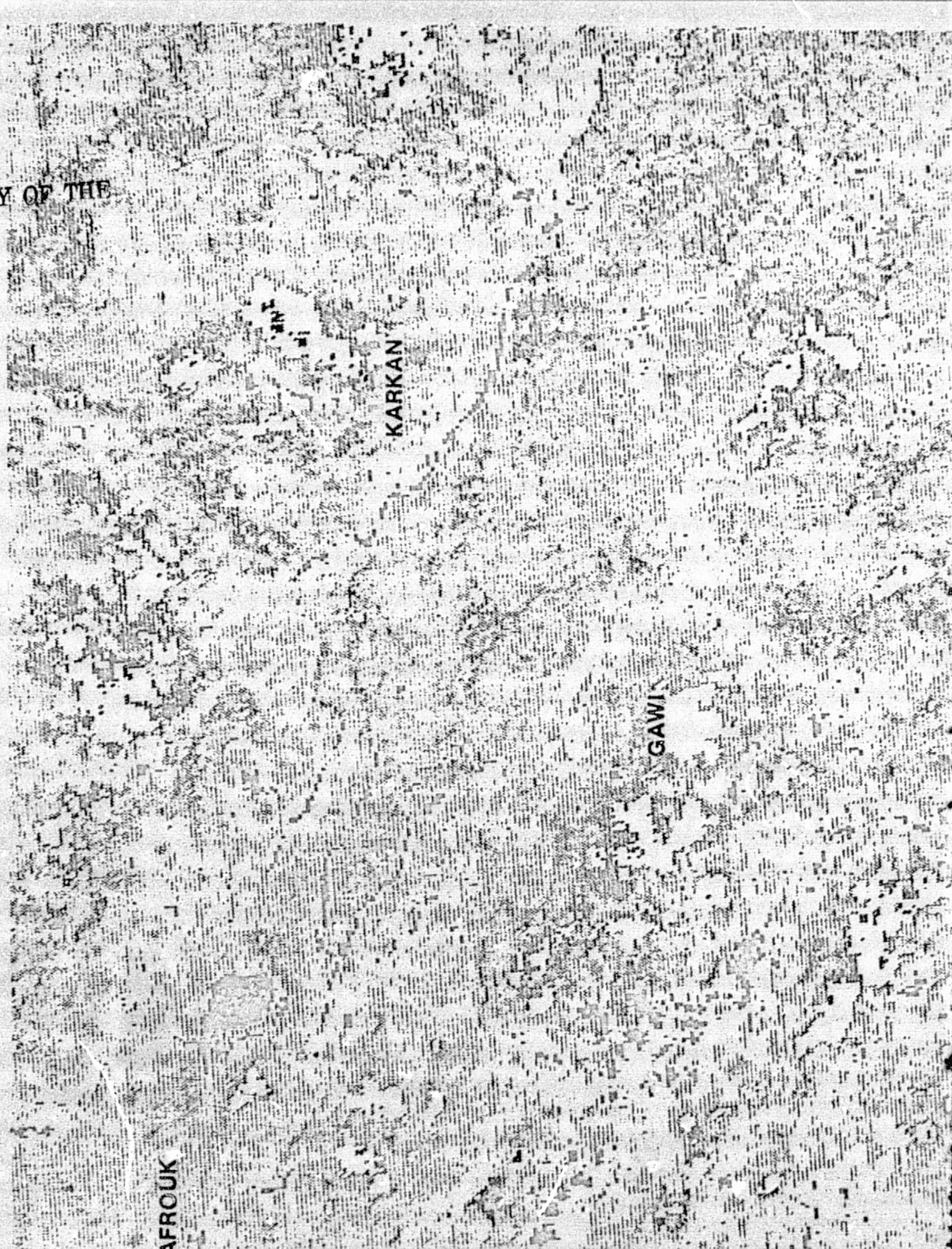

AFROUK
FOLDOUT FRAME



FOLDOUT FRAME 2

REPRODUCIBILITY OF THE
ORIGINAL PA

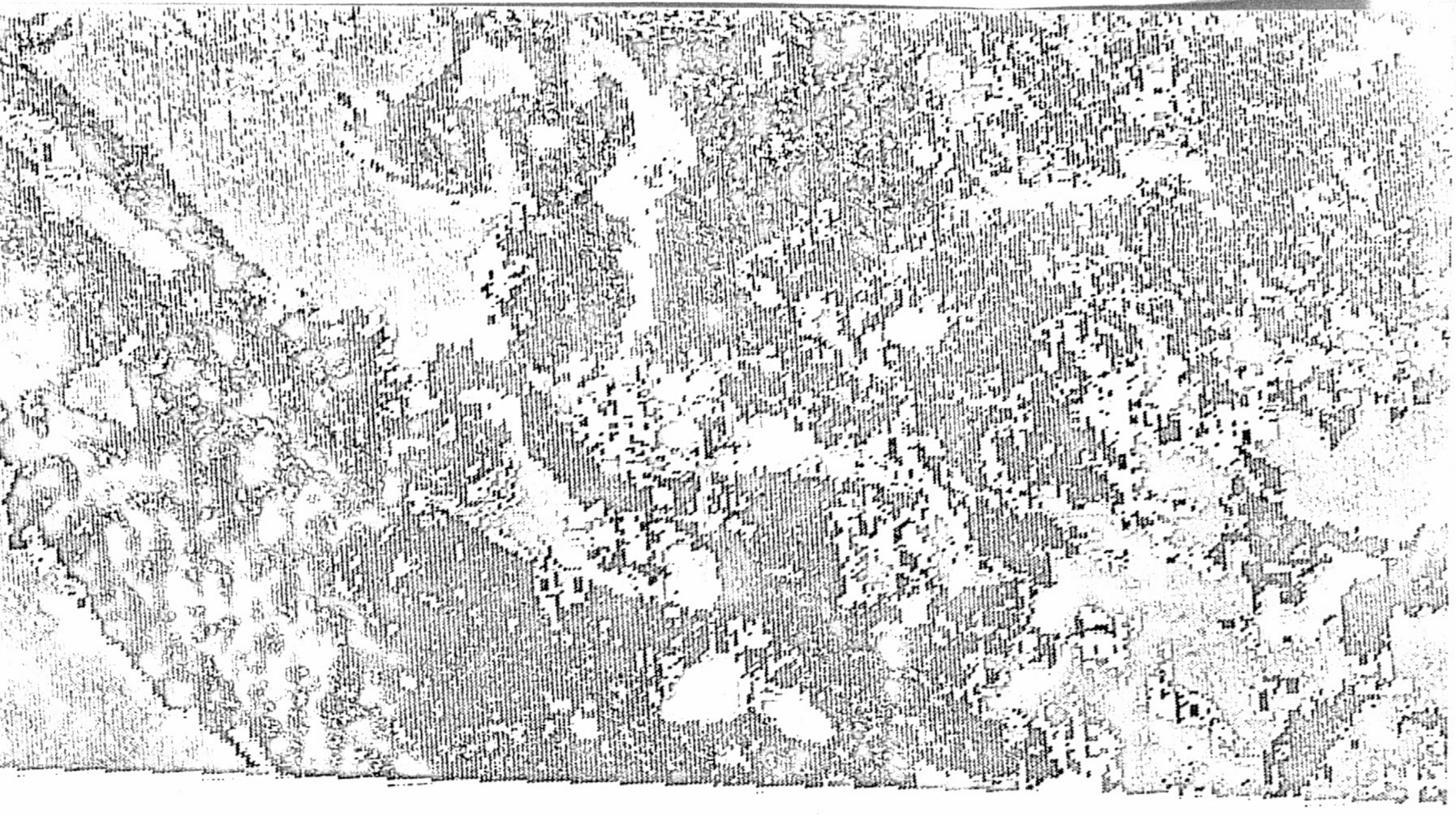


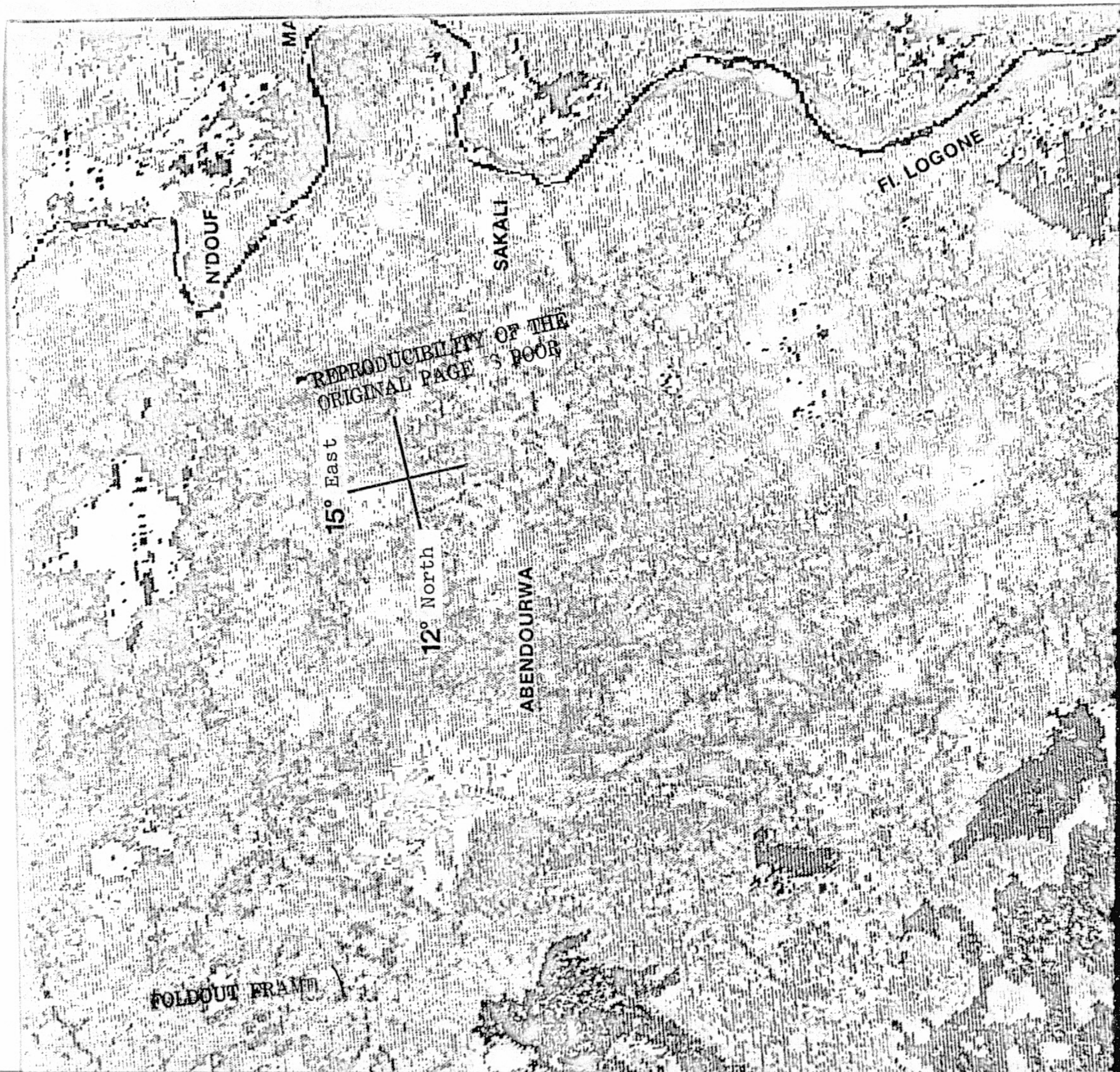
FOLDOUT FRAME

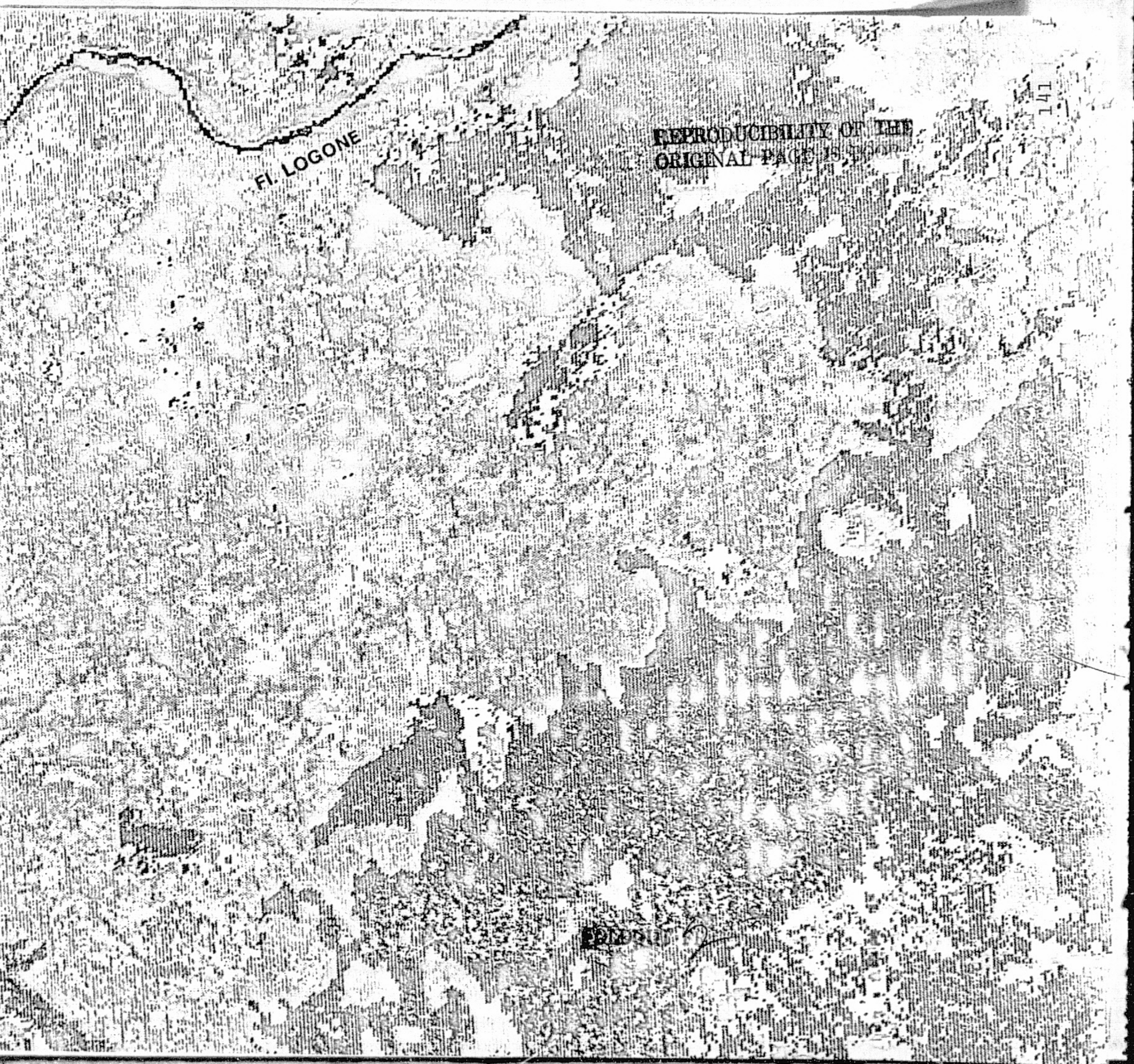

GAWI
MENA
Fl. CHARI
N'DOUF

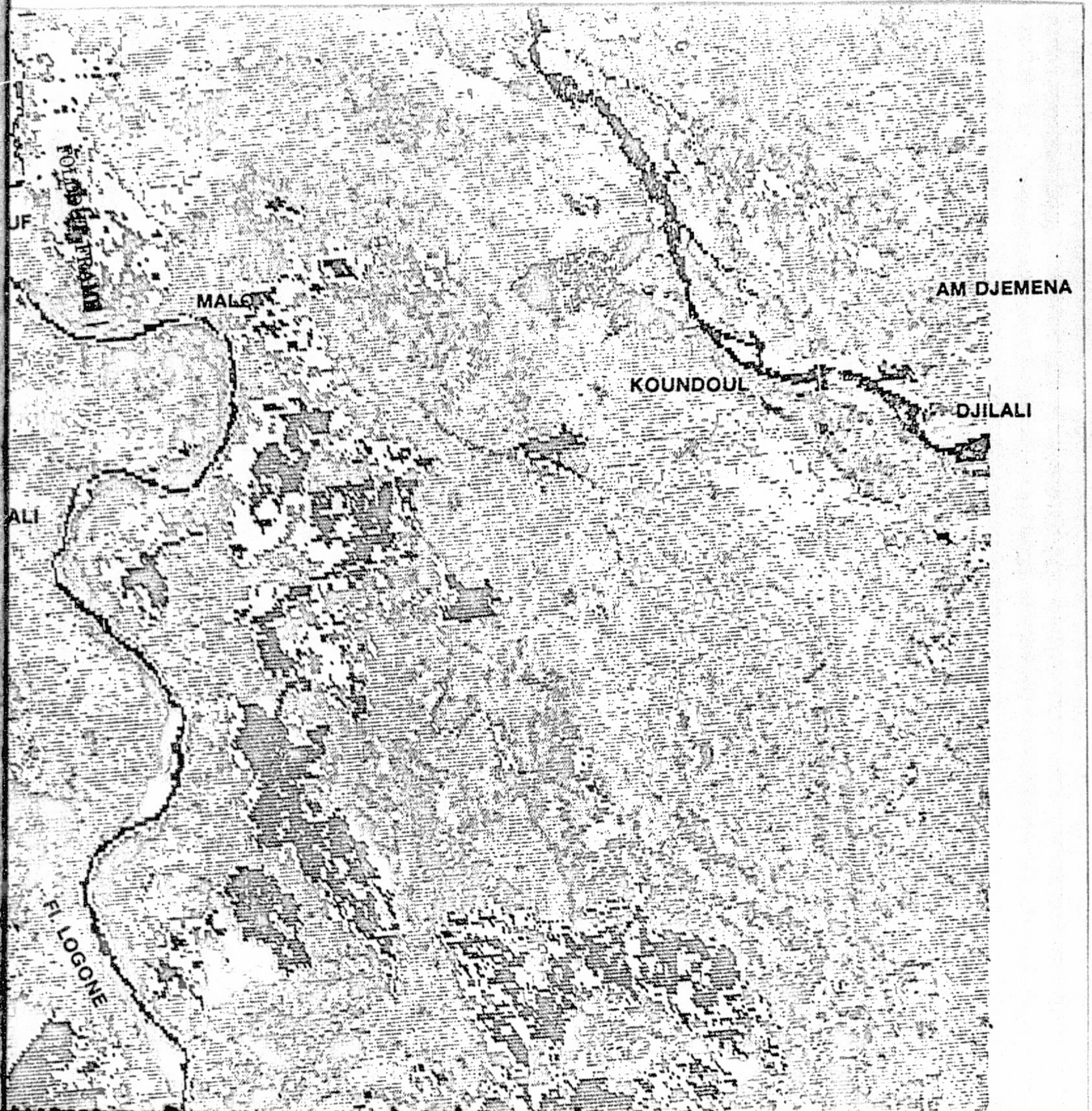
Scale: 1/100 000°

FOLDOUT FRAME




MA
N'DOUF
SAKALI
Fl. LOGONE
15° East
12° North
ABENDOURWA


Fl. LOGONE


AM DJEMENA
KOUNDOUL
DJILALI
MALO
FI. LOGONE

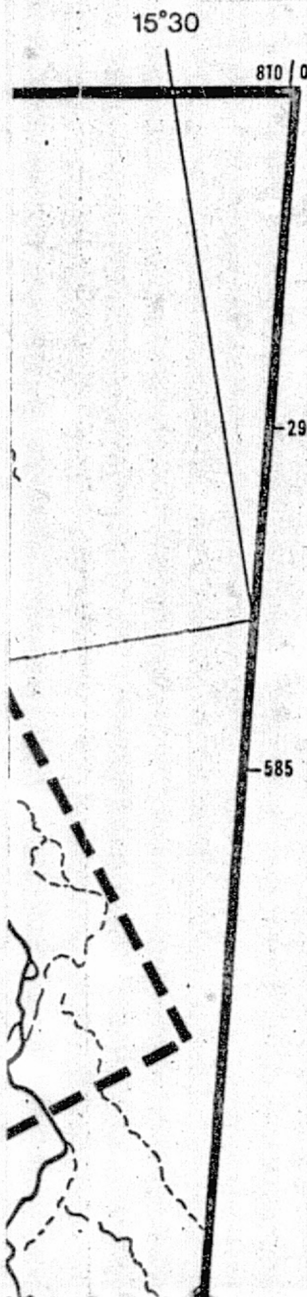

Rampelberg - Imprimé en France - Dépôt légal 1530 Octobre 1977
LOGONE GIRNI
Fl. LOGONE

Feuille 01
Décembre 1976

FOLDOUT FRAME

PROJECT LANCHAD.

Landsat 1 satellite image of the N'Djamena area, Scale 1/500,000.



Covered Area

(1) Enlargement by 1/200,000 (sheet 02)

(2) Enlargement by 1/50,000 (sheet 03)

- the photographic enlargements were made by Mr. Husberg and Gaudin, Photography Laboratory of the CNRS - Cartography

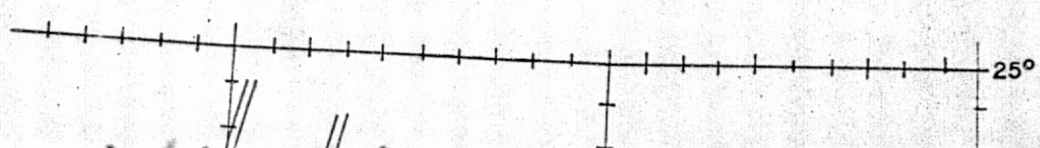
- Photo Interpretation and Analysis Supervised by M. C. Bardinet, Cartography Laboratory, University of Chad

- Non-supervised analysis by M. Monget - ENSMP Armines.

- Research Director - Professor F. Verger - EPHE-CNRS.

N1 - C1 - nov. 72
N2 - C2 - janv. 73
N3 - C3 - fév. 73
N4 - C4 - oct. 75
N5 - C5 - 75
N6 - C6 - jan 75

Center lists - C
Nadirs - N
Traces - T
Hours - H
Altitudes - A



- Non-supervised analysis by M. Monget - ENSMP Armines.

- Research Director - Professor F. Verger - EPHE-CNRS.

N1 -	C1 -	nov. 72
N2 -	C2 -	janv. 73
N3 -	C3 -	fév. 73
N4 -	C4 -	oct. 75
N5 -	C5 -	75
N6 -	C6 -	jan 75

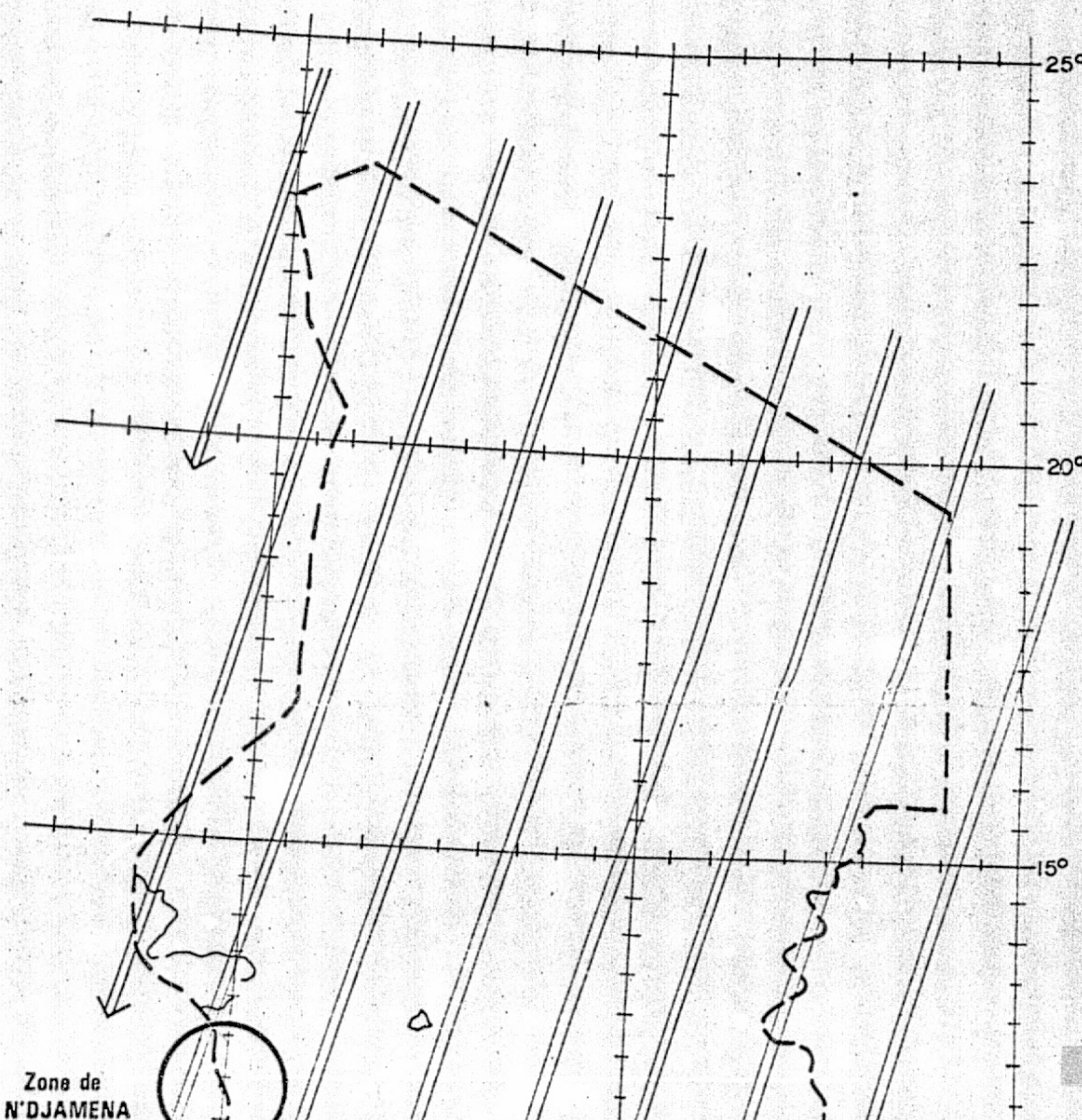
Center lists - C

Nadirs - N

Traces - T

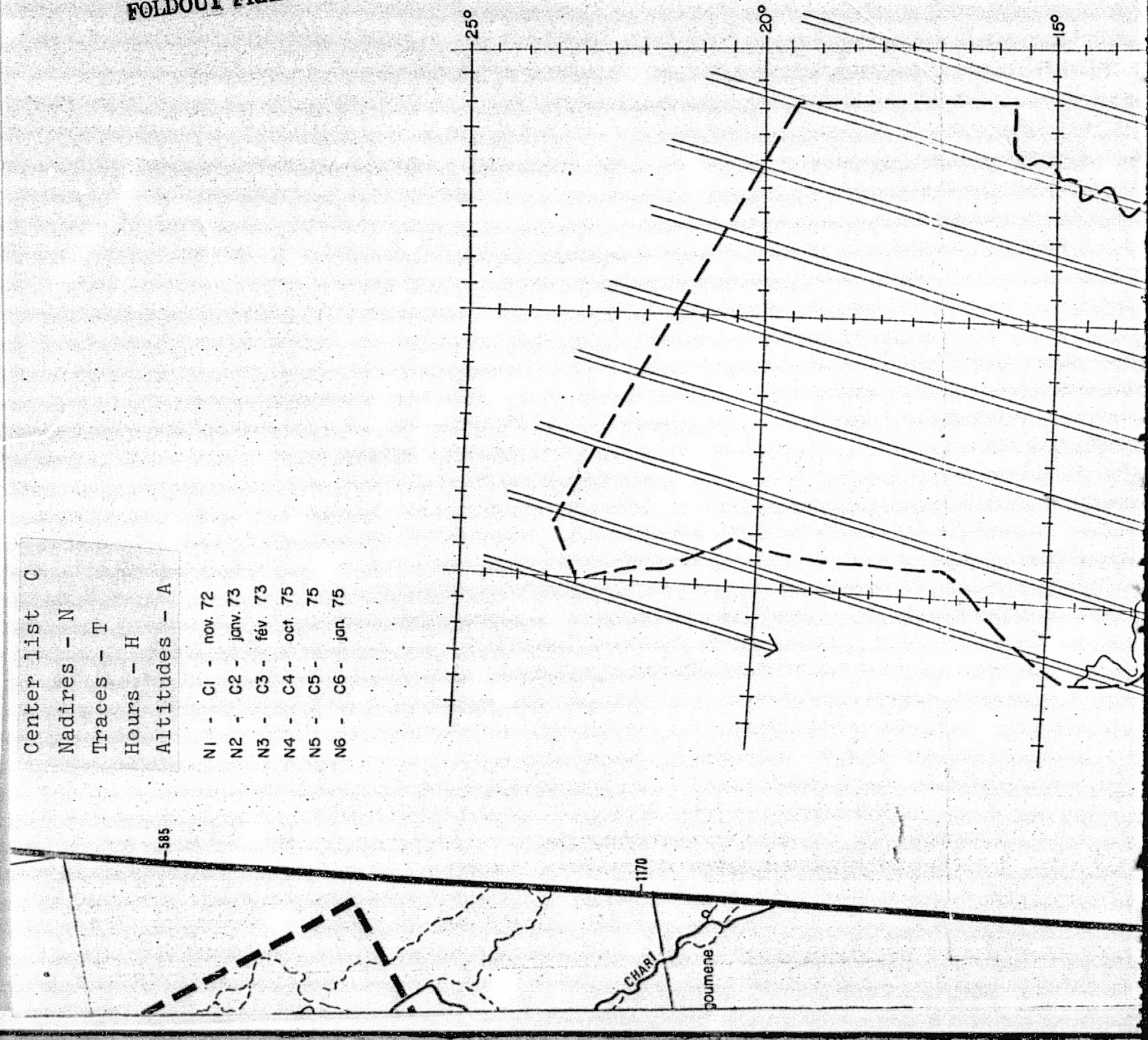
Hours - H

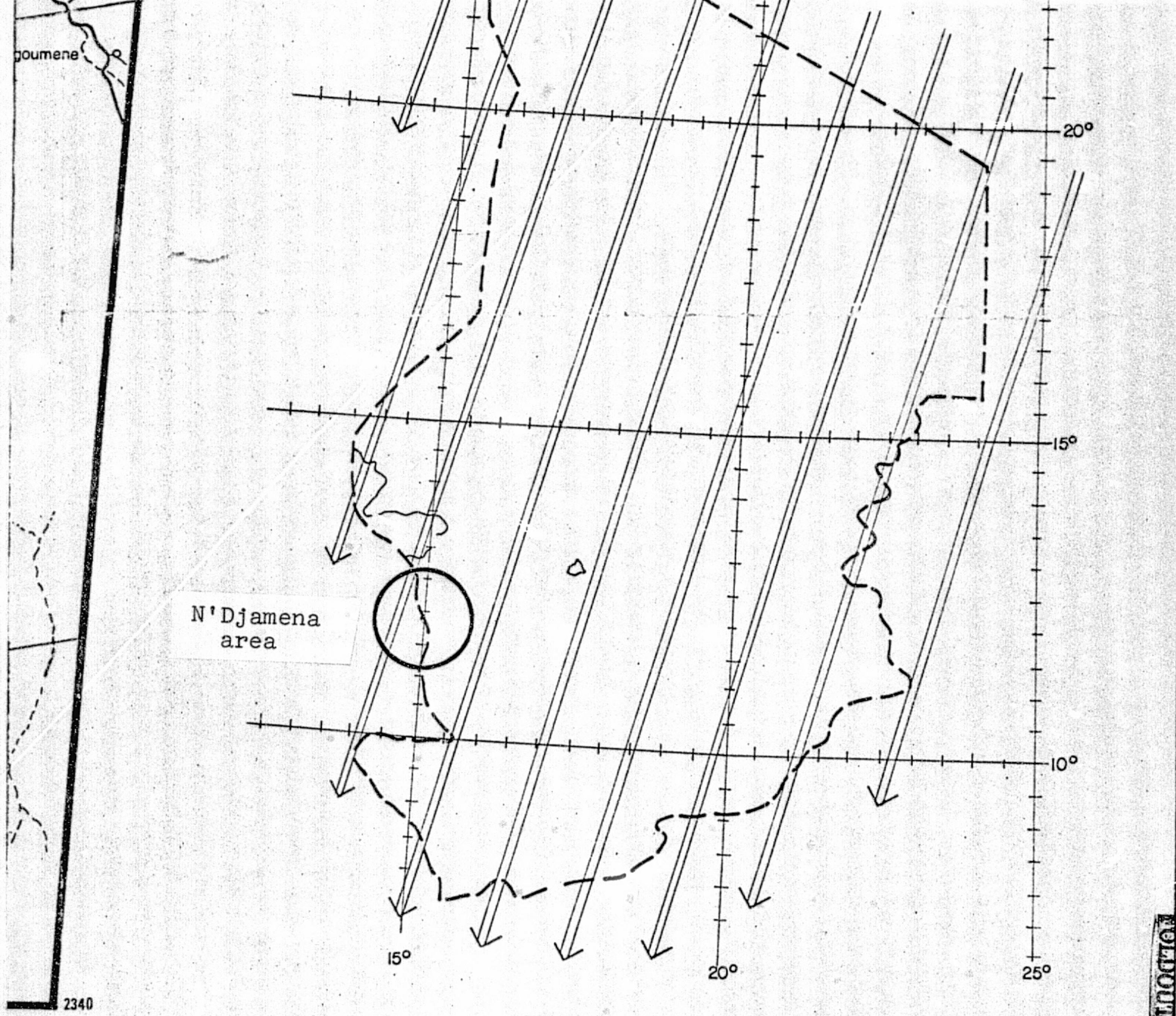
Altitudes - A



FOLDOUT FRAME 2

FOLDOUT FRAME





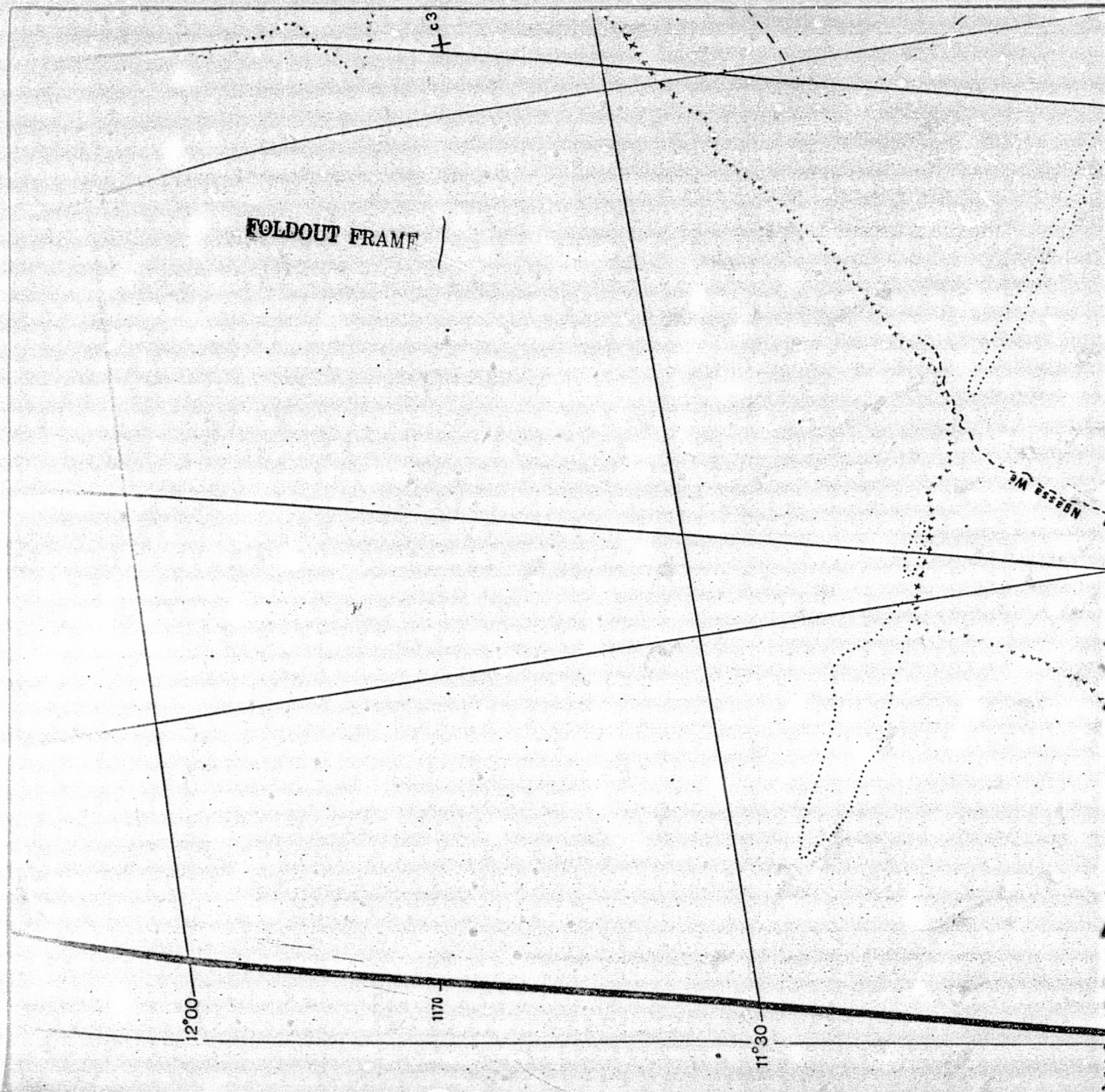
TCHAD

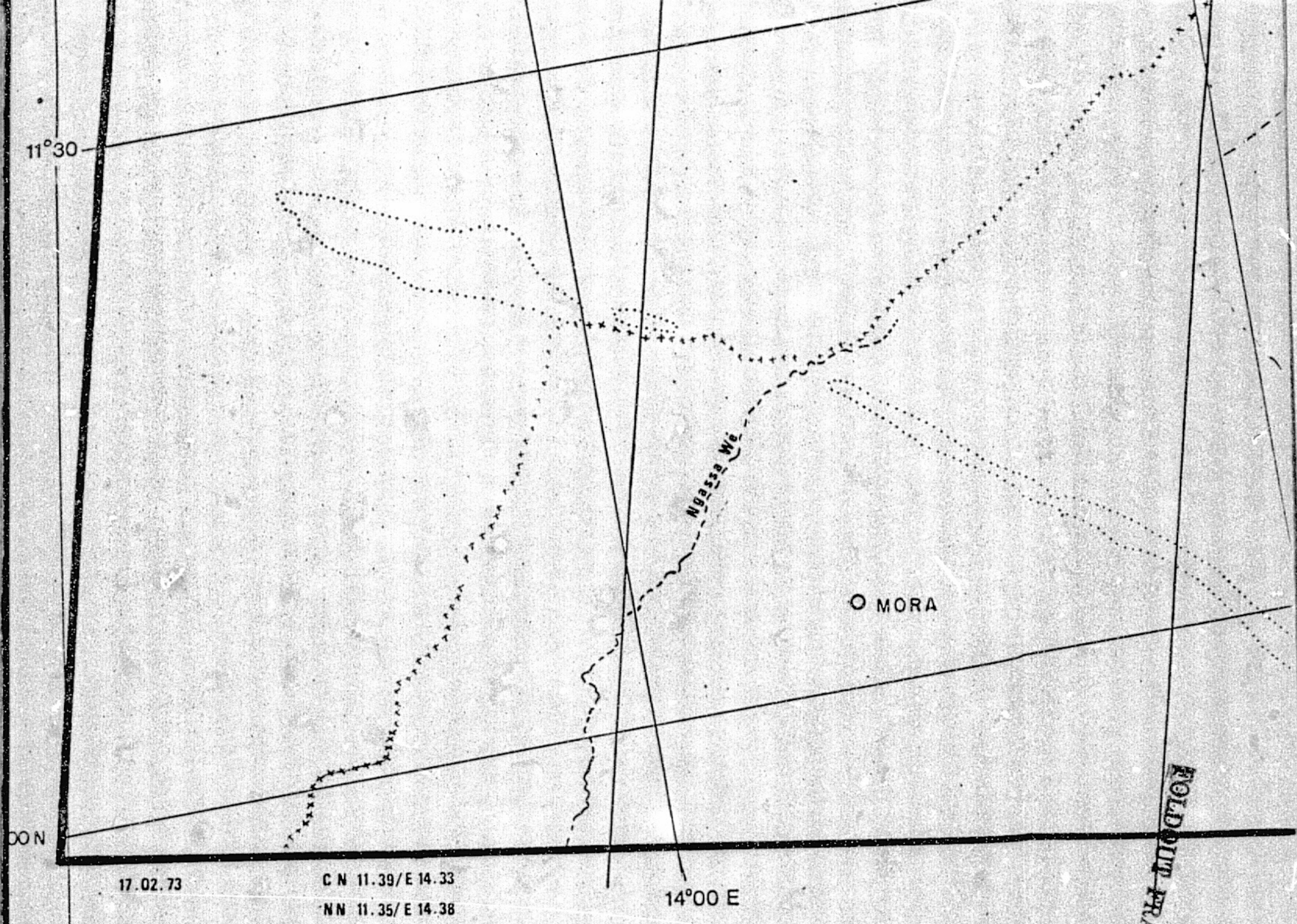
Orbital-LANDSAT - 1 traces

SOURCE: Earth Satellite Corporation
747 Pennsylvania Av. N.W.
Washington D.C. 2006

FOLDOUT FRAME 2

FOLDOUT FRAME

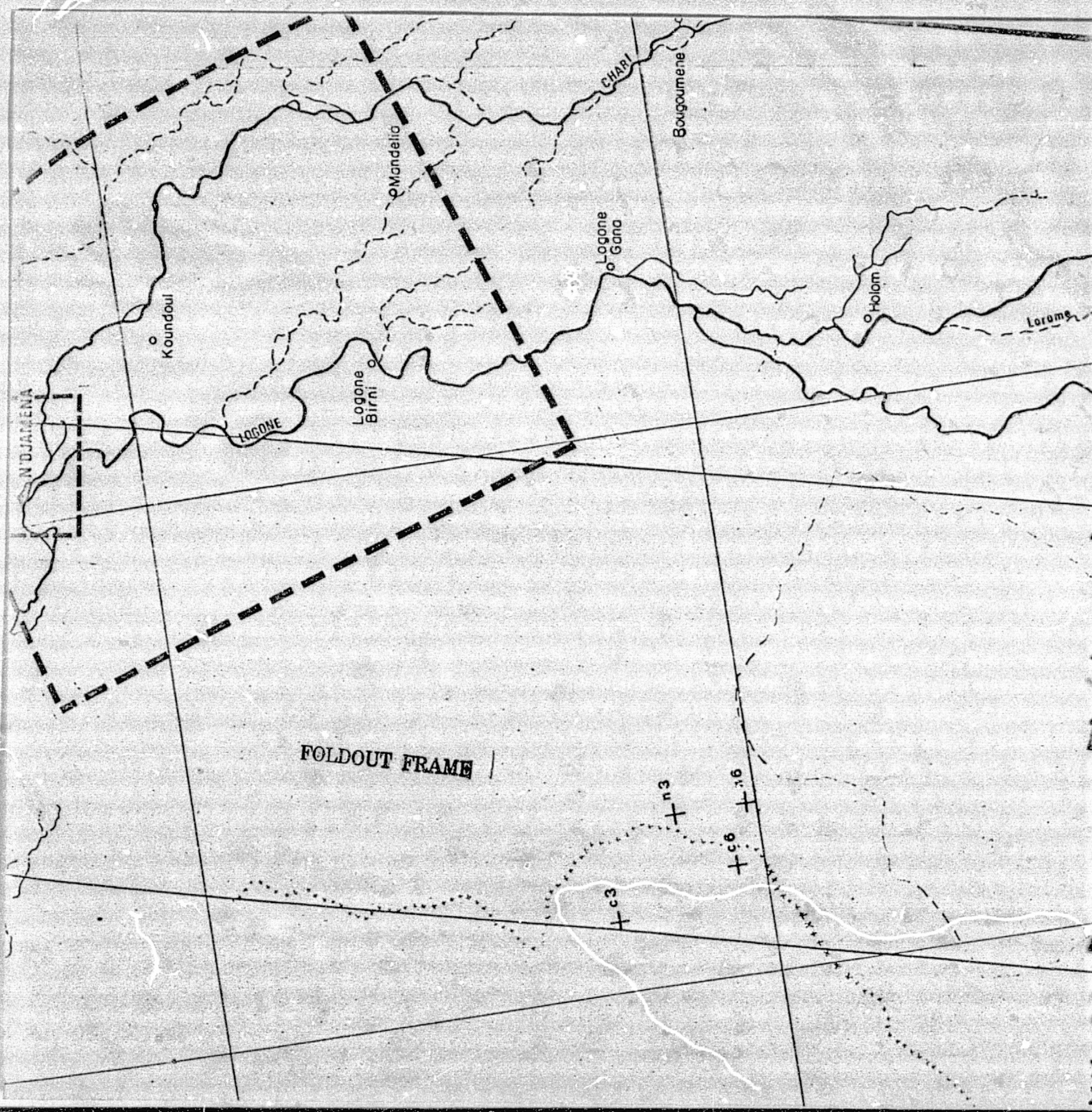




FOLDOUT FRAME 2

Superficie couverte par l'image : 185 km x 185 km = 34 225 km^2
soit 100 mille marin carré

06 janvier 1976
CN 11.32 / E. 14.35
NN 11.31 / E. 14.38



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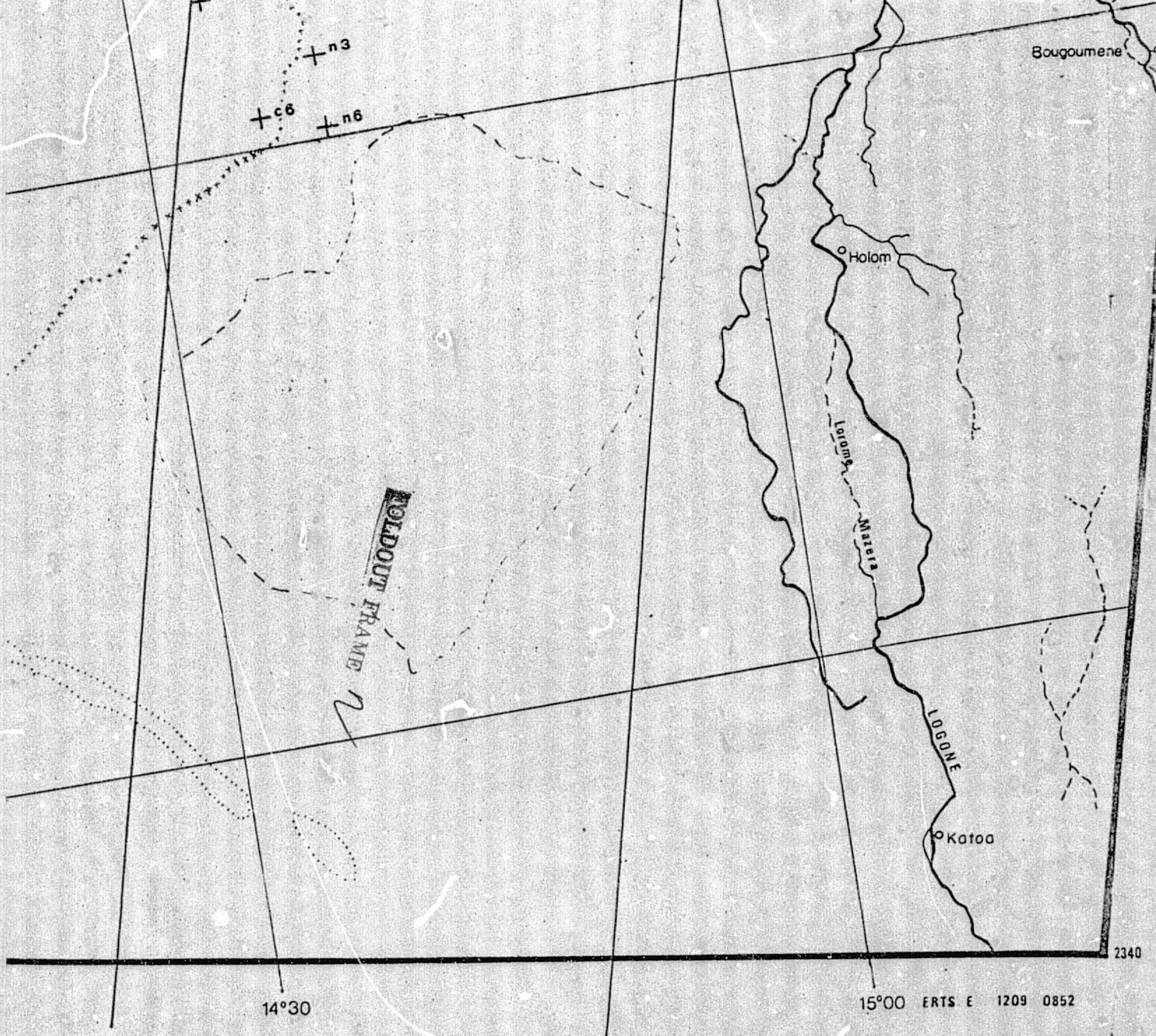
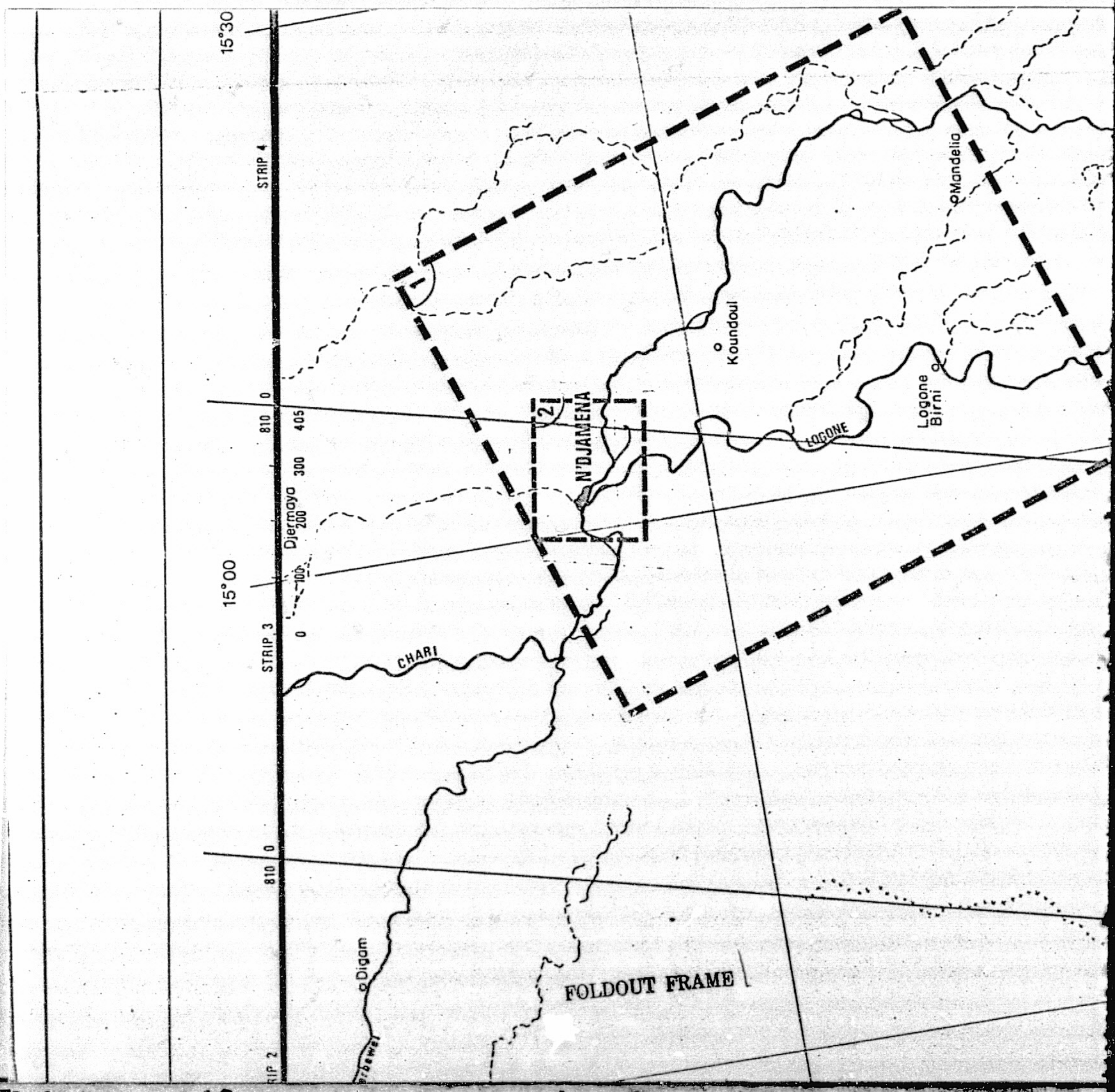

Bougoumene
Holom
Lorome
Mazera
LOGONE
Katoa
n3
c6
n6
2340
14°30
15°00
ERTS E 1209 0852



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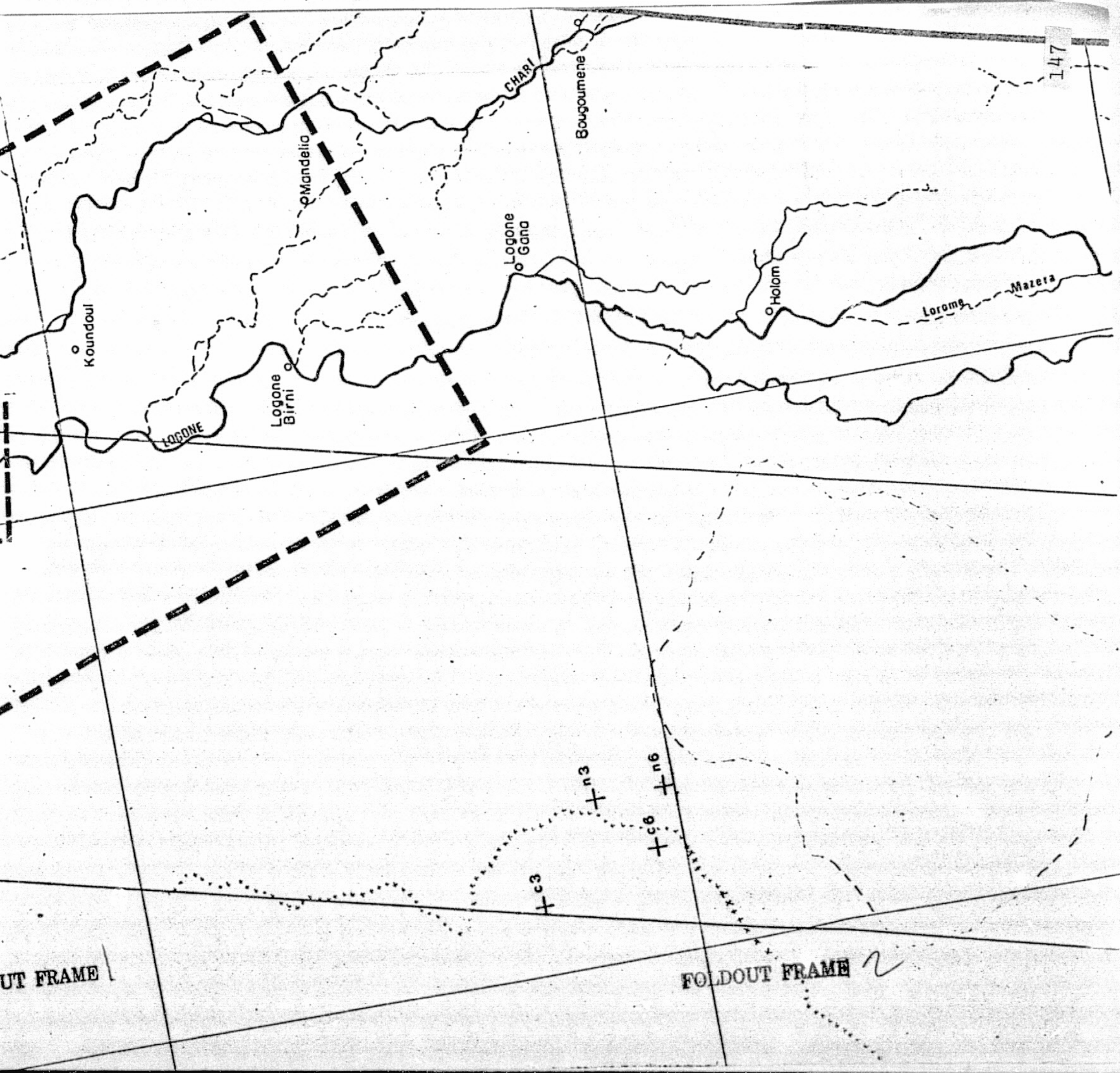
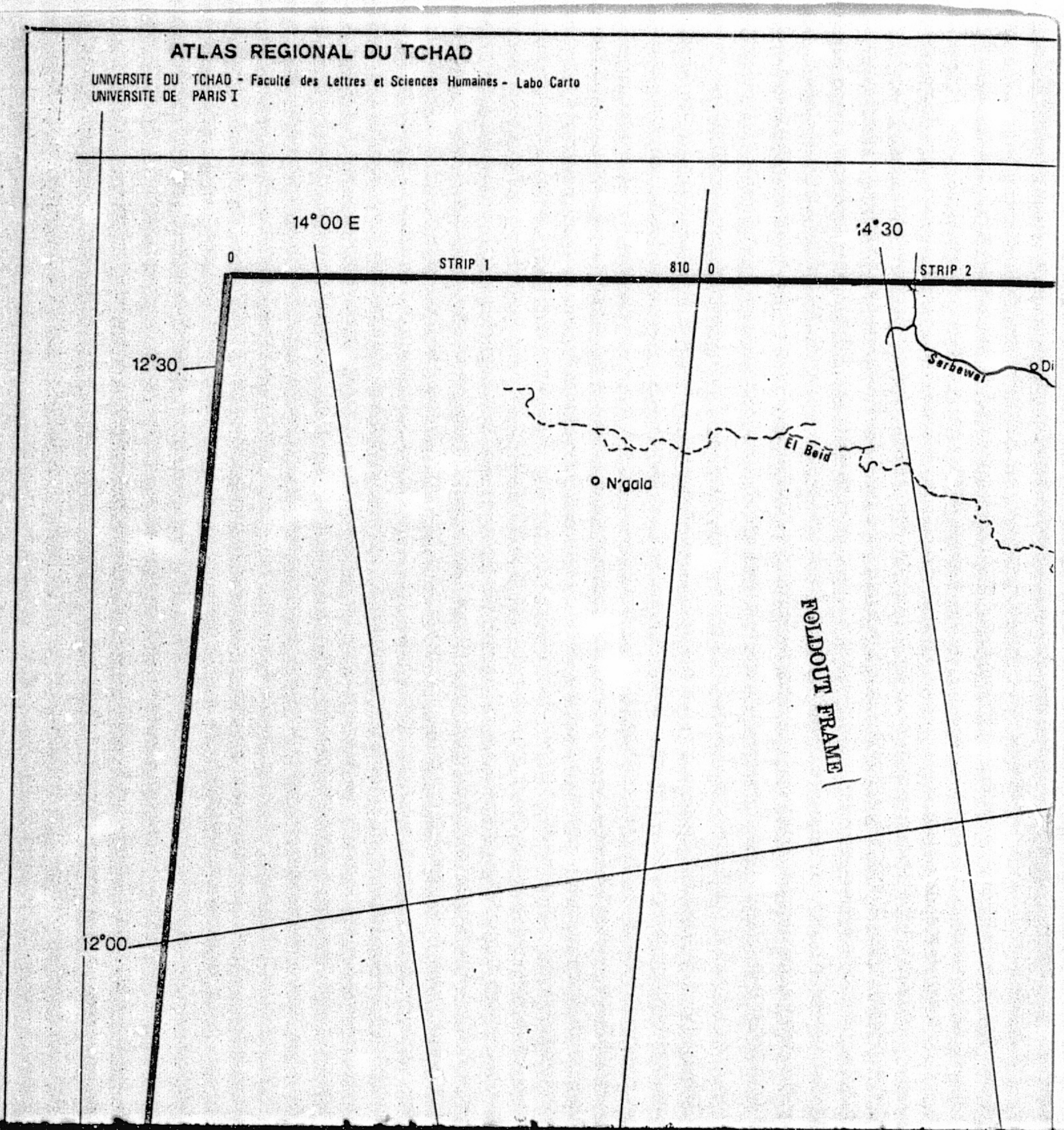


UT FRAME 1

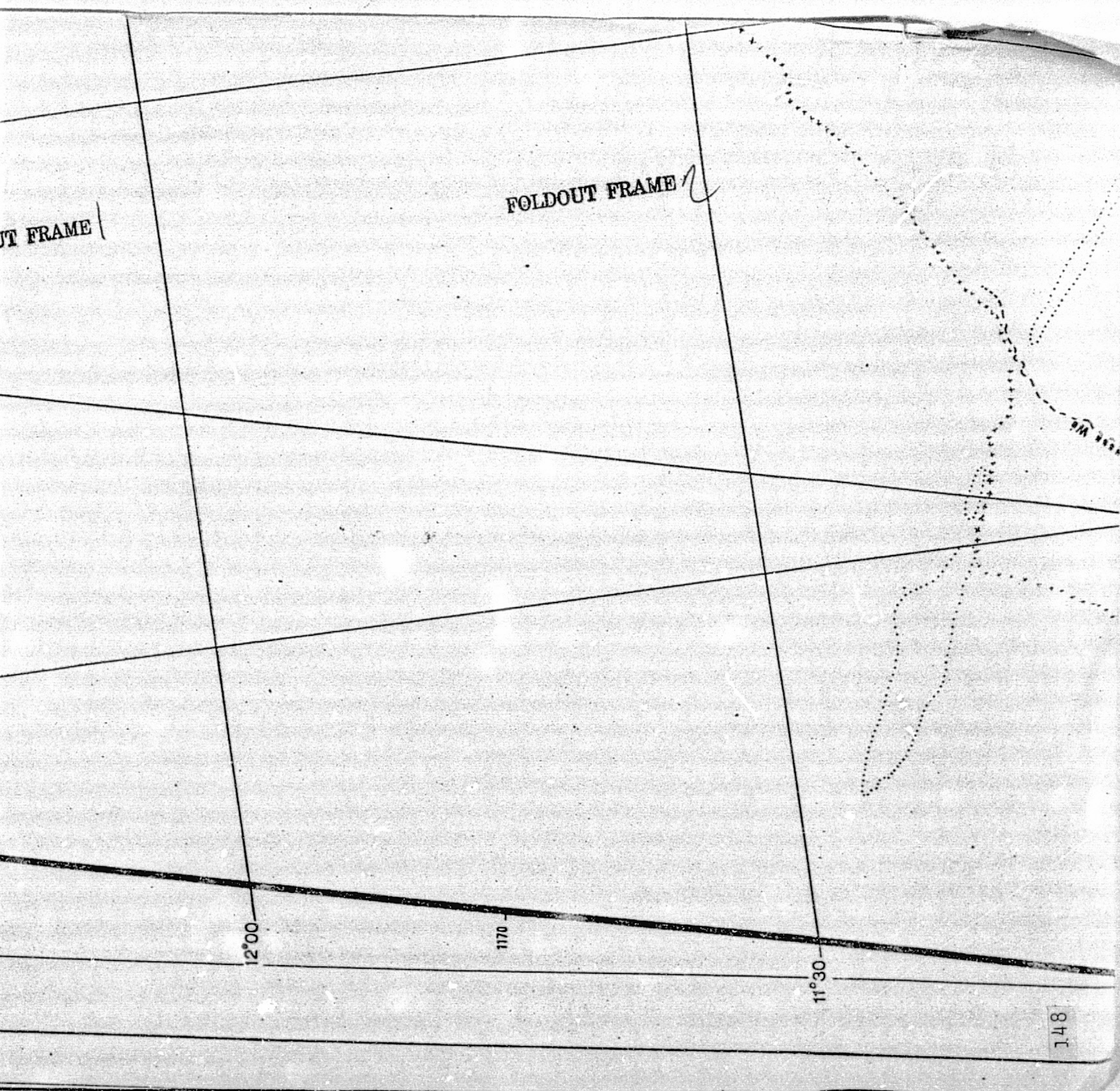
FOLDOUT FRAME 2



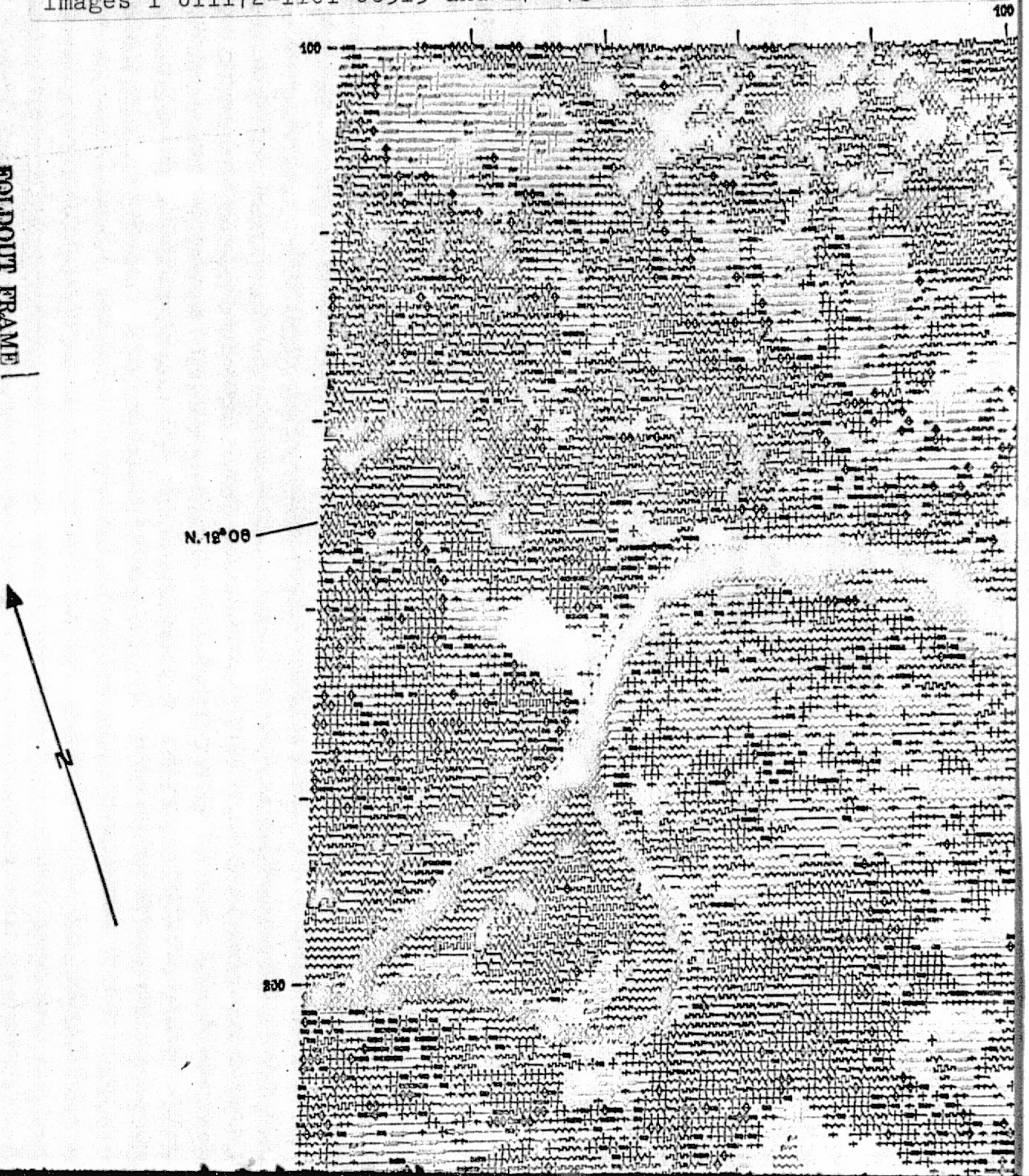
ATLAS REGIONAL DU TCHAD
UNIVERSITE DU TCHAD - Faculté des Lettres et Sciences Humaines - Labo Carto
UNIVERSITE DE PARIS I
14° 00 E
14°30
0
STRIP 1
810
0
STRIP 2
12°30
12°00
Serbewel
Di
El Beid
N'gala
FOLDOUT FRAME

UT FRAME 1

FOLDOUT FRAME 2



Product of the team Fralit - C. Bardinet, J. M. Monget,- 1977
Atlas Lanchad, N'Djamena, 1/50,000 - Diachronic FOR 1.2, Landsat
Images 1 011172-1101-08515 and 170273-1209-08521.



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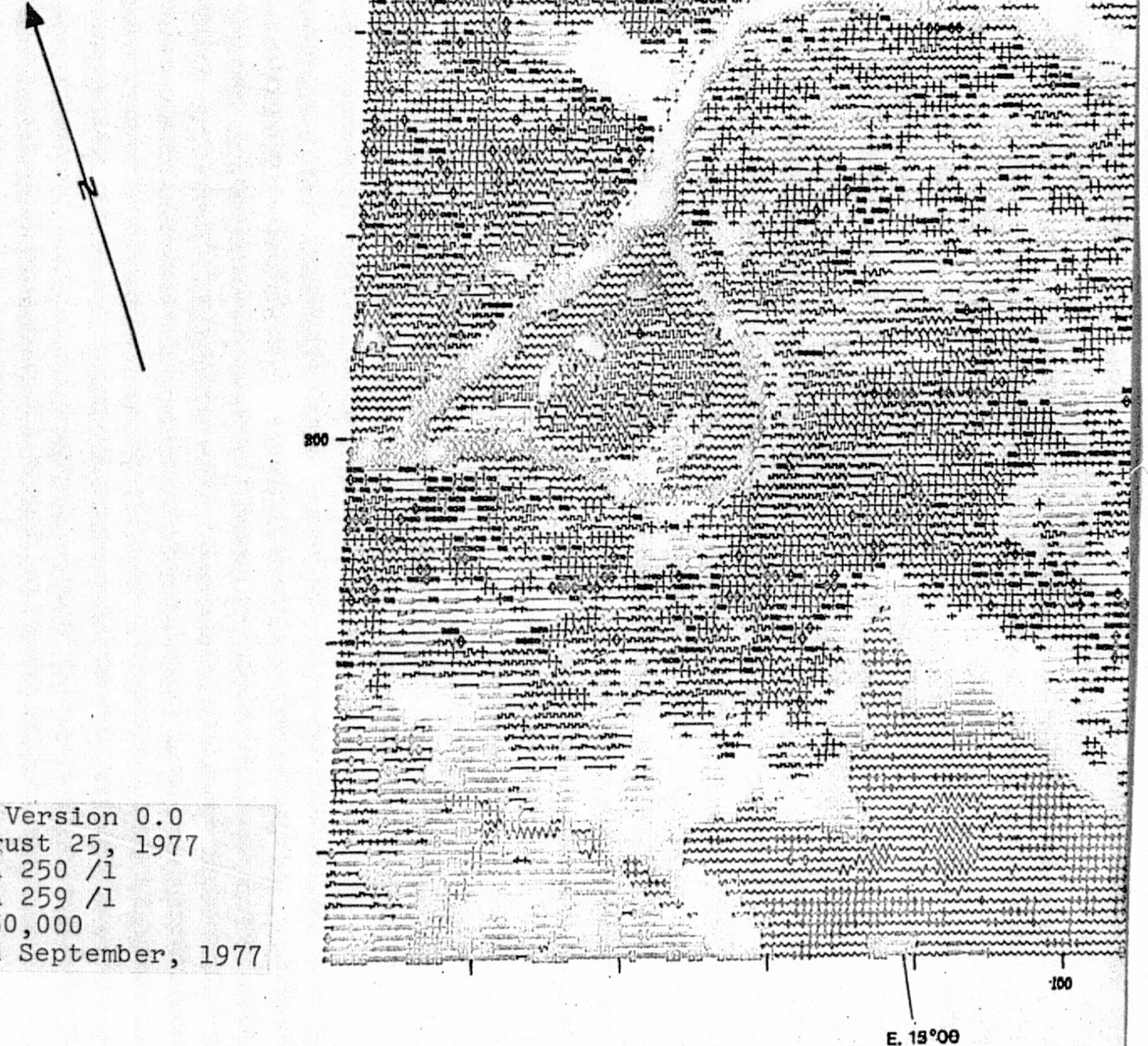

Fracarte - Version 0.0
FOR 1.2 August 25, 1977
Lines 100 A 250 /1
Columns 1 A 259 /1
Scale: 1/50,000
Produced in September, 1977

FOLDOUT FRAME

Paris University - Tchad University
Interuniversity Agreement
LANCHAD Atlas - Regional Chad Atlas